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ANALYSIS OF NOISE IN US ARMY AIRCRAFT.(U)

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Tape recordings were made of acoustical and electrical noise in the crew compartments and on the interphone lines of 7 models of U. S. Army aircraft, during flight operations. The data were analyzed to determine noise and speech levels in the communication channel, especially at crew members' ears. Calculations were then performed to

- Estimate hearing damage risk and
- Estimate the intelligibility of speech.

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The purpose of the project was to identify harmful noise levels and sources in the communication channel and to make recommendations for reducing such noise.

At frequencies below about 1000 Hz, noise in the communications channel is due primarily to ambient noise which enters the circumaural earcup through leaks between the cushion and the head. Above 1000 Hz, the noise in the channel is due primarily to ambient noise which is picked up by the microphone and transmitted to the earphone. Between 72% and 89% of the A-weighted noise at the ear is due to leakage into the earcup. In the aircraft, the earcup provides about 10 dB less attenuation than is measured with the same type earcup in the laboratory. The difference is due to the quality of the fit, and to the effects of interference from eyeglasses or sunglasses, and hair. Electrical noise from radios and interphone sets is not a significant cause of excessive noise in the communication channel.

The hearing damage risk calculations show that less than 1% of air crewmen would suffer more than a 10 dB hearing loss at speech frequencies after 10 years of flight duty. This is based on 4 hours per day of flight. Typical inter- and intra- aircraft speech intelligibilities were predicted to be greater than 95%.

Economic and performance constraints are prohibitive for achieving significant decreases of noise levels within helicopters, so dependence on ear protectors probably will continue. Most helicopters are in compliance with the current military specification for regulation of noise levels within aircraft (MIL-A-8806A). However, due to earcup leakage, noise exposure typically exceeds limits specified by the Army's TB MED 251. There is evidence that crew members are exposed to damaging noise levels during military basic and advanced training and during leisure-time activities. A recently adopted U. S. Army program provides a sequence for preventing hearing losses by removing a person from duty in a high-noise environment before serious hearing losses occur.

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1.0 INTRODUCTION

The purpose of this project is to analyze and interpret acoustical and electrical data which have been provided by the U. S. Army Avionics Research and Development Activity (AVRADA), Ft. Monmouth, NJ. The acoustical data are in the form of magnetic tape recordings of acoustical noise or speech, measured in 7 different types of U. S. Army aircraft during typical in-flight operations. Some of the electrical data are in the form of magnetic tape recordings of electrical noise on voice communication lines in those same aircraft. The remainder of the electrical data are in written form and are data from standard electrical tests of individual items of communication gear in the same aircraft. The data were analyzed to determine noise and speech levels in the communication channel, especially at the pilot's or crewman's ear. Calculations were then performed to:

- Estimate hearing damage risk
- Estimate the intelligibility of speech
- Estimate the effect on hearing damage risk or intelligibility of changing the noise in selected elements of the channel.

A further purpose of this project is to identify harmful noise sources and levels affecting the communication channel. The principal objective of the project is to determine the contribution of the communication channel to aviator hearing loss and to recommend measures to reduce or eliminate this contribution. Another important objective is to recommend measures to improve the intelligibility of speech.

A study by the U. S. Army Medical Research and Development Command estimates that from 30 to 50 percent of all personnel in the infantry, artillery, armor, and aviation branches suffer noise - induced hearing loss during their military careers.[1] In 1970, the Veterans Administration paid compensation of approximately 52 million dollars for hearing loss, presumably sustained in military service.

The noise levels in many, if not most, types of military aircraft are hazardous to the unprotected ear.[2-4] Measures to significantly reduce the sound at the source, or to attenuate it before it reaches the cockpit or cabin area, have in the past imposed unacceptable performance penalties or required yet-to-be-developed design advances. Personal hearing protection and administrative controls are used to conserve hearing.

This project has been structured so that the performance of aircraft communication systems is measured while in operations use. Thus, one can see whether the communication components work as well in service, with regard to intelligibility and hearing conservation, as they do in the laboratory.

The tape recordings and electrical measurements were made at Ft. Hood, TX and Ft. Eustis, VA by personnel from AVRADA and from the American Electronics Service Corporation (AEL). The recordings were made between September 1976 and April 1977, inclusive.

2.0 DESCRIPTION OF THE COMMUNICATION ENVIRONMENT

Measurements were made in 37 individual aircraft, including 7 different models.

No. of Aircraft	Model	Wing Type	No. of Engines
10	UH-1H Iroquois (Huey)	Rotor	1
6	OH-58A Kiowa	Rotor	1
6	OV-1D Mohawk	Fixed	2
3	AH-1S Hueycobra	Rotor	1
3	AH-1Q Hueycobra	Rotor	1
3	CH-47C Chinook	2 Rotors	2
6	CH-54B Tarhe	Rotor	2

All aircraft are powered by turboprop or turboshaft engines. The manufacture dates range from 1966 to 1973, inclusive. More detailed descriptions are found in Appendix A.

The aircraft radios and intercommunication sets (AIC) are a mix of SLAE (Standard Lightweight Avionics Equipment) and PRE-SLAE. The SLAE AIC is the C-6533 which was used in 15 aircraft. The PRE-SLAE C-1611D was used in 22 aircraft. Additional information about the avionics complement is found in Appendix C.

Figure 1 is a block diagram of the communication system, applicable to either the C-1611D or C-6533. The circled items identify possible sources of noise which will ultimately appear as masking or damaging audio frequency noise at a crewman's ears. The C-1611D headset amplifier is capable of delivering about 100 mW of low-distortion speech to each earphone, providing about 97 dB SPL at the ear. At higher levels, the distortion increases rapidly. At the point where limiting occurs, a sound pressure of about 100 dB SPL is produced at the ear. The C-6533 can deliver somewhat higher low-distortion signal to each earphone producing about 100 dB SPL at the ear. It is estimated from a few measurements made during the project that at least 104 dB SPL can be produced at the ear before limiting occurs. Higher levels are possible in frequency bands where the earphone has response peaks. The C-6533 has a softer limiting characteristic than the C-1611.

The air crewman's helmet worn during the flight tests was the Model SPH-4. The helmet contains plastic earcups which have circumaural ear cushions filled

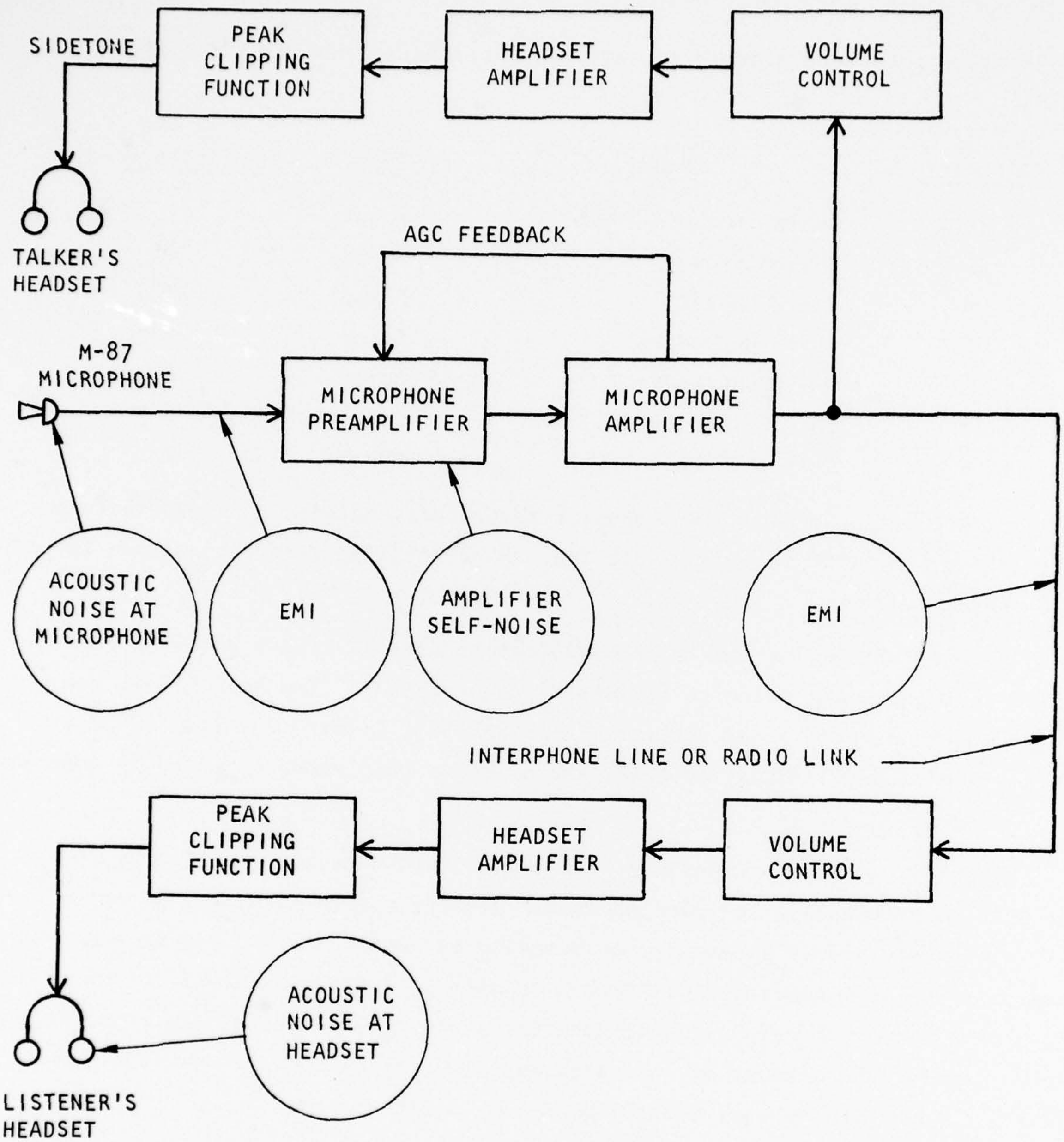


FIGURE 1. BLOCK DIAGRAM OF COMMUNICATION SYSTEM

with soft foamed plastic. Each earcup contains a Model H-143/AIC earphone.[5] The earphones are electrically connected in parallel. The specified impedance of each earphone at 1000 Hz is 19 ± 2 Ohms. All in-the-earcup acoustical data were taken in the same SPH-4 helmet in the right-hand earcup. The response of the H-143 earphone was measured by AVRADA and is shown in Figure 2. The response is considered to be typical.

Those data segments which include speech were made with a boom-mounted, noise-cancelling microphone, Model M-87/AIC.[6] The microphone impedance is 5 ± 2 Ohms. Various individual M-87's were used. They were observed to operate normally, but were otherwise not calibrated. Figure 2 also shows the close-talk response of a nominal M-87 microphone, as specified by MIL-M-26542A[6] at a test distance of 1/4 inch.

Figure 3 shows the amplification characteristics of the C-1611, which is very similar to the amplification characteristic of the C-6533. Also shown is an overall response of the communications system, including microphone, AIC, and earphone.[7]

During the planning of the data acquisition phase, lists of relevant flight modes and communication system test points were developed.

Flight Modes (Standard Maneuvers)	Communication System Test Points
1 Take-Off	1 Cabin Ambient (acoustic)
2 Climb	2 Earcup, interphone not keyed (acoustic) (NO KEY)*
3 Descent Right	3 Earcup, interphone keyed, no processed speech (acoustic) (KEY NO TALK)
4 Climb left	4 Earcup, interphone keyed, with processed speech (acoustic) (KEY TALK)
5 Descent left	5 Earcup, interphone not keyed, dummy headset (electrical)
6 Climb Right	6 Earcup, interphone keyed, dummy headset (electrical)
7 Descent	7 Earcup, interphone keyed, dummy microphone dummy headset (electrical)
8 Level Flight	
9 Hover at Altitude	
10 Hover in Ground Effect	
11 Land	
12 Nap of Earth Flight	

* See Appendix C, page C-1 for definitions of Key and No Key conditions.

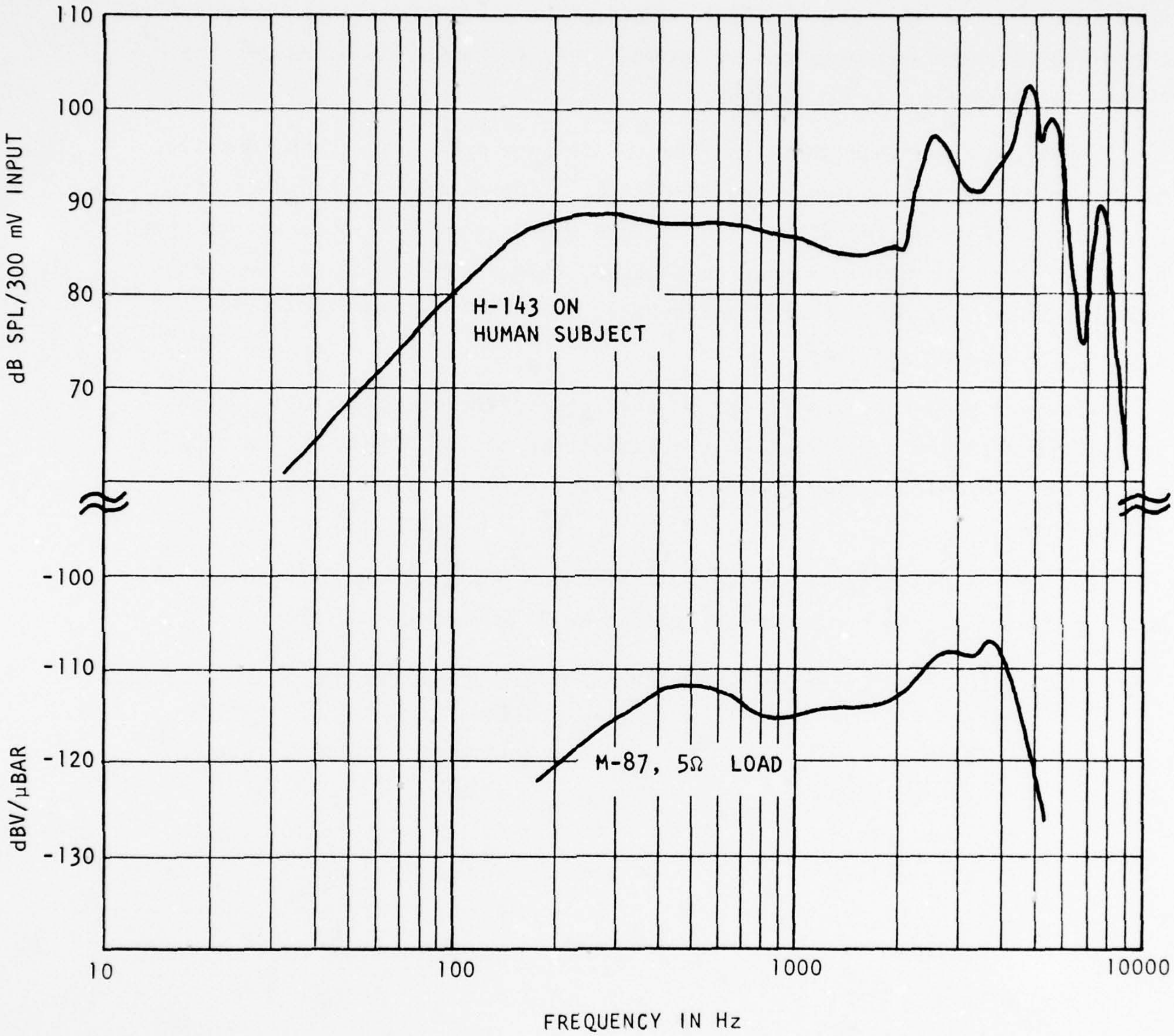


FIGURE 2 (TOP) RESPONSE OF TYPICAL H-143 EARPHONE ON HUMAN SUBJECT (AVRADA) MEASUREMENT)

(BOTTOM) RESPONSE OF M-87, AS SPECIFIED BY MIL-M-26542A (USAF) (20 DECEMBER 1962)

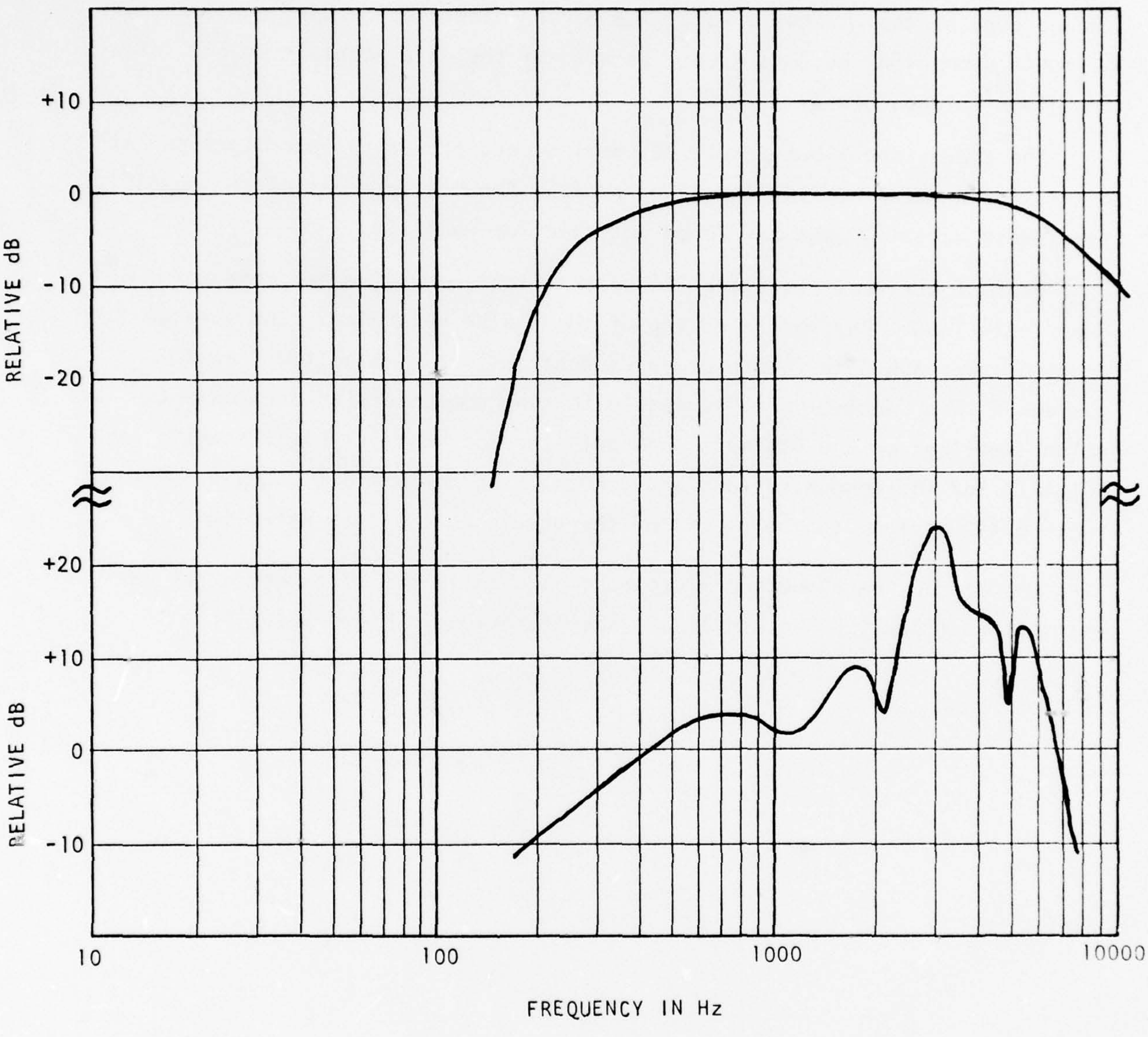


FIGURE 3 (TOP) RESPONSE OF C-1611/AIC (AVRADA MEASUREMENT)
(BOTTOM) OVERALL RESPONSE OF MICROPHONE, AIC, AND HEADSET (AVRADA) MEASUREMENT)

The cabin ambient noise was tape-recorded on one channel of a magnetic tape recorder using a microphone in the aircraft cabin. The earcup acoustical recordings were simultaneously made on the other channel using a microphone inside the earcup, at the crewman's ear. The earcup electrical recordings were made across a dummy (8Ω) headset load. Details of the data acquisition and format are given in Appendix B.

The above conditions permit 72 combinations of earcup recordings per aircraft, for a total of 2664 for 37 aircraft. About 22 percent of the possible total were actually made and found suitable for analysis.

Each of the tape recordings for each flight condition and test point was one minute long. During the making of the "talk" recordings, the speaker (crew or pilot) was asked to read a prepared text, referred to as the "rainbow passage," in a "normal voice" suitable for the communication environment. The volume settings on the AIC sets were adjusted for "comfortable listening level" suitable for the communications environment. In most or all cases a mid-range setting (12 o'clock to 1 o'clock) of the volume control was selected.

The earcup, earphone and microphone package in the SPH-4 helmet is designated the MK-1564 ( )/AIC. The applicable specification is MIL-H-55351(EL).

3.0 DESCRIPTORS OF THE ENVIRONMENT

3.1 A-WEIGHTED NOISE

The electrical output of microphones and associated audio amplifiers often is passed through an electrical filter which is designed to approximate the frequency-dependent response of human ears to sound. Such a filter is called an A-weighted filter. Figure 4 shows the frequency-dependence of the response of such a filter.[8]

The overall level of A-weighted sound has been found to be useful for calculating the impact of noise on human beings, where that impact may be interference with activities, annoyance, physiological effects, or risk of hearing loss.[9] The use of a single number for overall A-weighted sound as a descriptor of risk of hearing loss is based on the assumption that sound that cannot be heard cannot damage an ear.[9] A related assumption is that A-weighting accounts for the frequency dependence of an ear's susceptibility to damage, so that a given A-weighted level for a discrete frequency sound produces the same hearing loss regardless of the frequency of that sound.

The A-weighted sound levels which are tabulated in this report were produced by playing back magnetic tape recordings of helicopter noise through an analog A-weighting filter (Bruel & Kjaer Type 2111 Spectrometer) and supplying the electrical output of that filter to a B&K Type 2305 graphic level recorder. Values of A-weighted sound levels were read from the resulting strip charts of sound level versus time. The resulting levels were calibrated by means of a 250 Hertz tone corresponding to a known sound pressure level which was recorded on the magnetic tapes during the initial measurements. Listings of the output of the Articulation Index computer program (See Appendix D) which appear in several places in this report include calculated A-weighted sound levels. Those levels generally agree to within about 2 dB with the levels that were determined with a B&K filter and a level recorder. Calculations of Articulation Index like those described in Section 3.4 do not incorporate A-weighted sound, but weighting factors similar to A-weighting are built into the calculations.

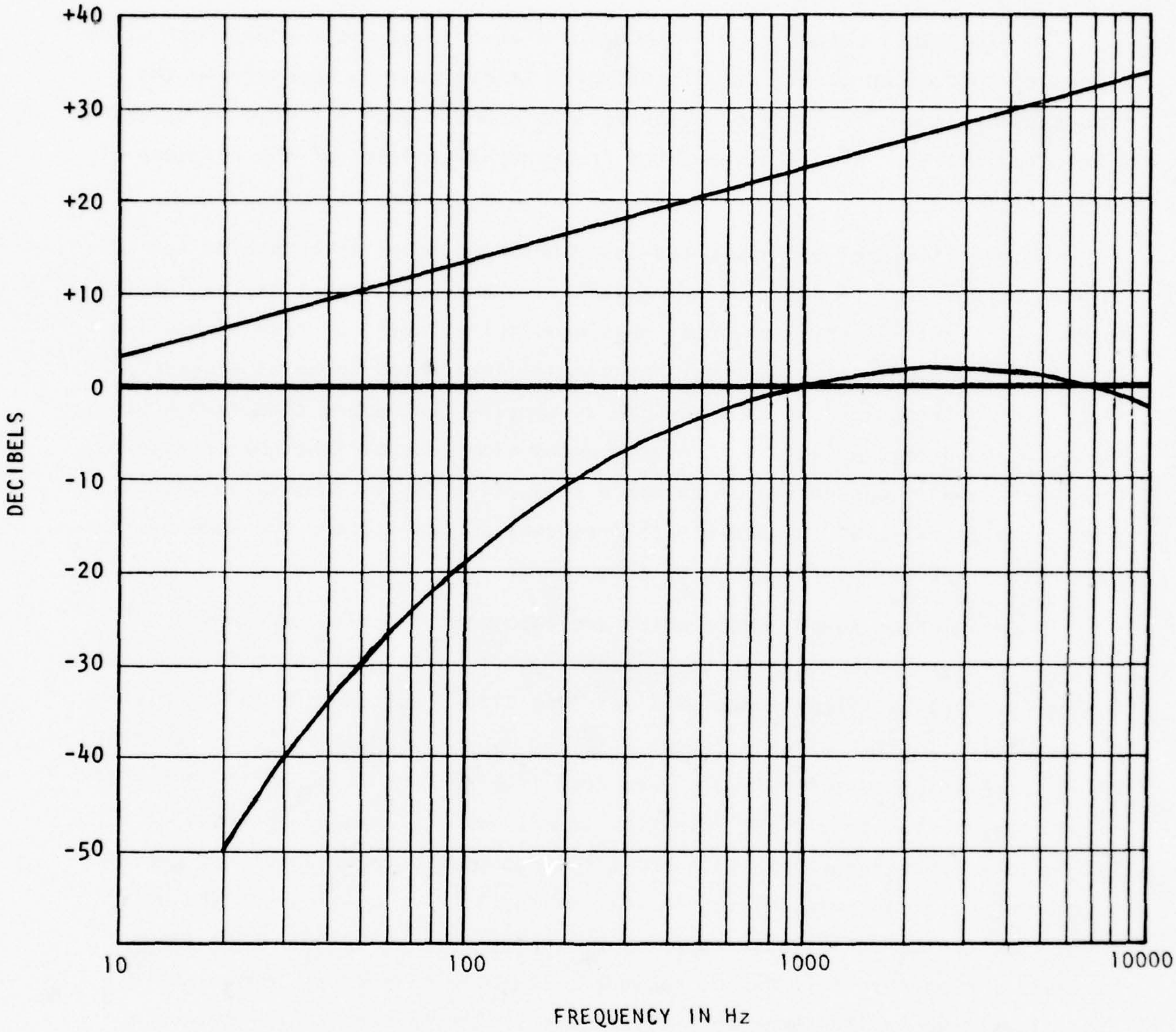


FIGURE 4 WEIGHTING CURVES:
TOP CURVE: SPECTRUM LEVEL TO 1/3-OCTAVE LEVEL
BOTTOM CURVE: A-WEIGHTING CURVE

3.2 POWER SPECTRUM LEVEL VS FREQUENCY

The plots of power spectrum level versus frequency which are presented in this report were produced by a Hewlett Packard Model 5451A Fast Fourier Transform (FFT) system. The Model 5451A utilizes an electronic digital computer to calculate Fourier transforms of time-varying signals. Those Fourier transforms are used to calculate power spectrum levels for narrow bands of frequencies throughout a frequency range of interest.

The method of analysis is as follows. A section of taped data for a given test and flight condition is processed using Fourier analysis to determine a power spectrum. The tape sections are 1-minute long; however, the effective averaging time for the analysis is about 40 seconds because the A/D conversion is a little slower than real time. The excellent repeatability of the results indicate that the accuracy would not be improved by averaging for a full minute. The effective filter bandwidth for the analysis is 10 Hz. The results are stored as a list of numbers representing the mean-square voltage in each of the 10-Hz bandwidths required to cover the frequency range of interest, which is 20 Hz to 10000 Hz. Division of the numbers by 10 yields a pseudo power spectrum, corresponding to a 1 Hz bandwidth. A 250 Hz calibration tone on the tape is also analyzed to derive a calibration scale factor. Its dimensions are $(\text{volts})^2/(\text{psi})^2$ where the (rms) psi is derived from the known sound pressure produced by the pistonphone used to make the calibration. If necessary, an additional scaling factor is applied to account for the setting of the input attenuator on the Nagra recorder. Any of the numbers in the stored list can then be converted to dimensions of $(\text{psi})^2$ by dividing by the calibration scale factor. Further processing yields dimensions of dB SPL, in whatever bandwidth is found useful.

3.3 HEARING DAMAGE RISK - PUBLISHED CRITERIA

In the following discussion of hearing damage risks, the threshold shifts which are cited are in addition to those shifts which normally occur due to the human ageing process.

Although there is some disagreement among hearing experts as to what comprises a threat of significant hearing loss,[10] there is general agreement that

measurable hearing loss results from frequent exposure to sound levels above 75 dBA for ten years or more.[9] For example, exposure to sound levels of 85 dBA for 8 hours per day, five days a week, for ten years will produce a noise-induced permanent threshold shift (NIPTS) of 19 decibels or more at 4000 Hertz in ten percent of people who are so exposed.[10] Exposure to 88 dBA for 4 hours a day or 91 dBA for 2 hours a day will produce that same loss of hearing, assuming that the noise is continuous without interruption. Even at levels as low as 75 dBA, 10 percent of the population will experience an NIPTS of 6 decibels or more at 4000 Hertz after 40 years of daily exposure.[10]

Judgements of the significance of the hearing loss just described are aided by noting that the average of NIPTS at 500, 1000, and 2000 Hertz resulting from daily exposure to 85, 90, and 95 dBA for 8, 4 and 2 hours per day, respectively, will be 3 decibels or greater, after 40 years, for 10% of the population.[10] It has become common practice to refer to such frequencies as "speech frequencies", implying that avoidance of hearing losses in that frequency range will prevent any serious speech communication handicap.[9] That premise is explicit in most occupational hearing damage-risk criteria, which treat hearing losses at frequencies above 2000 Hertz as insignificant for speech comprehension.[11] However, hearing at frequencies up to at least 3000 Hertz plays a major role in understanding of speech,[12] and speech sounds ranging from 200 to 6100 Hertz contain useful information.[11]

Differences in judgements of the importance of hearing at high frequencies are largely responsible for differences in proposed maximum allowed sound levels to protect hearing. For example, the Occupational Safety and Health Administration (OSHA) requires[13] that an employee's eight-hour time-weighted average exposure be no more than 90 dBA, while the Environmental Protection Agency (EPA) has recommended that OSHA reduce that limit at least to 85 dBA,[13] and the U. S. Army has adopted that reduced limit.[14] In another context, EPA has stated[11] that a limit of 73 dBA appears to be the rational choice if strict conservation of hearing is to be the criterion without consideration of cost. Much of the 17 dBA difference between OSHA's requirement and EPA's goal of 73 dBA is due to differences of opinions concerning the importance of hearing losses at 4000 Hertz.[10] The remainder of the difference is due to differing objectives in terms of the

percentage of the population that is to be protected. OSHA limits are designed to protect 90 percent of the population from NIPTS exceeding 5 decibels at "speech frequencies",[10] while EPA limits are designed to protect 100 percent of the population from NIPTS exceeding 5 decibels at 4000 Hertz.

EPA has taken the position that any measurable NIPTS at any frequency is unacceptable if the goal of regulations is to protect the health and welfare of people with an adequate margin of safety. However, EPA considers noise-induced permanent threshold shifts of less than 5 decibels to be unmeasurable and, therefore, not relevant. OSHA regulations are based on a judgement that a noise-induced permanent threshold shift of 7 or more decibels at "speech frequencies" for 10 percent of the population is acceptable, from which it may be inferred from NIPTS curves that NIPTS of 28 or more decibels at 4000 Hertz for 10 percent of the population is acceptable.[10] EPA's compromise of their ideal of 73 dBA for 100 percent protection to a recommendation for 85 dBA and the U. S. Army's acceptance of that limit[14] corresponds to acceptance of NIPTS of 3 or more decibels at "speech frequencies" and 19 or more decibels at 4000 Hz for 10 percent of the population, after 40 years of exposure. Actually, most of the loss suffered after 40 years of exposure is sustained during the first 10 years of exposure.

The Committee on Conservation of Hearing of the American Academy of Opthalmology and Otolaryngology defined a hearing handicap to be that condition which they judged to interfere with understanding everyday speech.[15] The threshold of handicap was defined by them to occur when the average of the hearing levels at 500, 1000, and 2000 Hz is 25 decibels above what they defined as normal hearing (International Standards Organization Standard, 1963). Although that is a popular criterion,[16] it may lead to significant underestimates of the severity of noise-induced hearing loss and overestimations of tolerable limits to exposure to noise.[15]

The Veteran's Administration (VA) allows no compensation unless a noise-induced permanent threshold shift (NIPTS) at "speech frequencies" exceeds 37 dB in a person's better ear, or exceeds 57 dB in their poorer ear.[17] Figure 5 shows that the VA criterion for the better ear corresponds to requiring a limit of 113 dBA to noise levels to which workers are exposed for 8 hours per day if

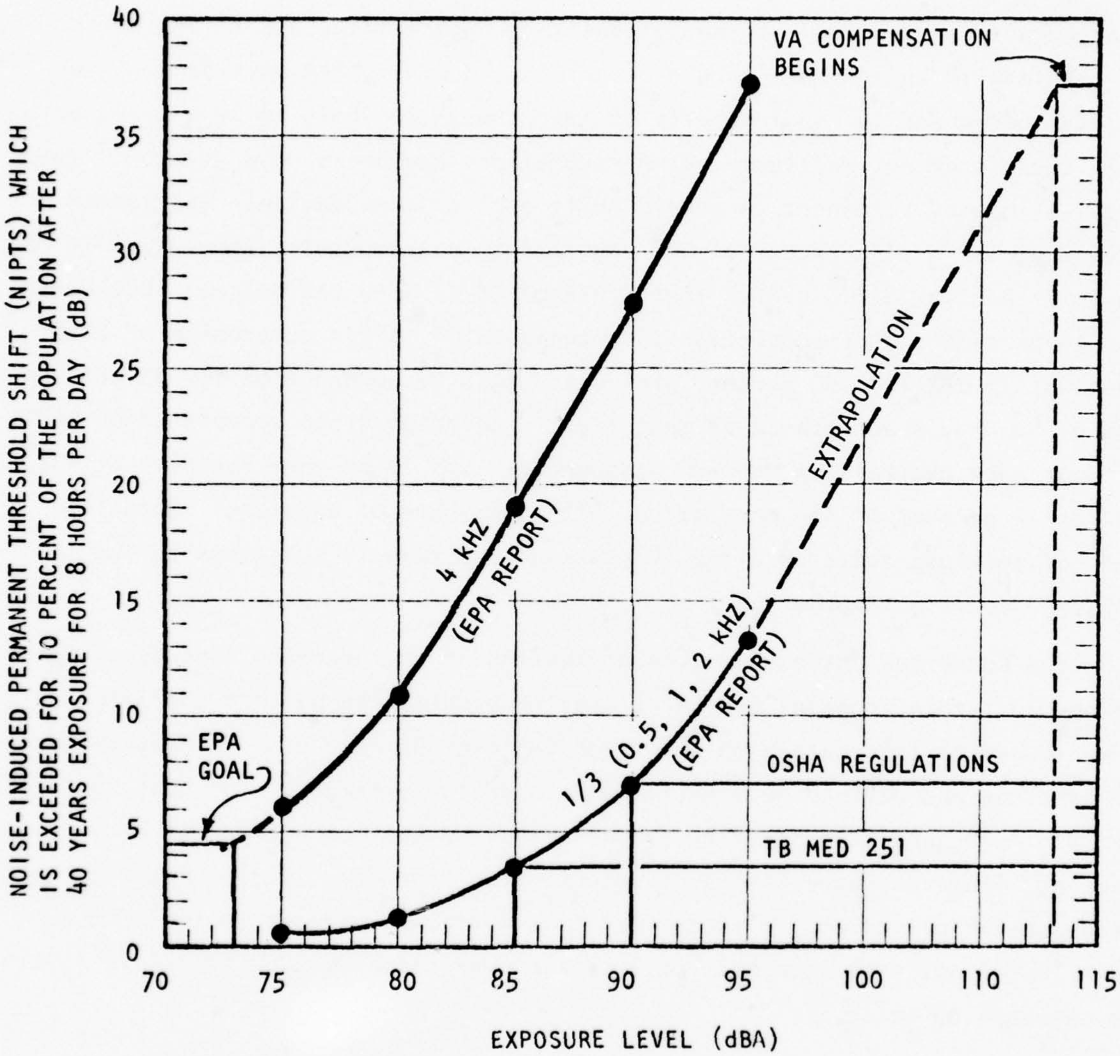


FIGURE 5. 90 PERCENT MAXIMUM NIPTS CURVE (NOISE-INDUCED PERMANENT THRESHOLD SHIFT VS. EXPOSURE LEVEL)

it is desired to protect 90 percent of employees. Figure 5 also shows EPA and OSHA criteria for comparison. The data shown in Figure 5 were taken from a report on NIPTS which was published by EPA.[18] Those data also were plotted and interpreted by von Gierke.[9]

Figure 5 does not provide any information about noise limits required to protect the ten percent of people who are most susceptible to hearing loss. Figure 6 provides that information. Part of the information in Figure 6 is from the EPA NIPTS report,[18] and part is from extrapolations and from Figure 5. The extrapolations which are displayed in Figures 5 and 6 are risky, as extrapolations always are. However, even if there is some inaccuracy in those extrapolations, the resulting curves still serve to put the problem of risk of hearing loss of helicopter pilots in perspective. No additional published data are available, so extrapolations are necessary for definition of the problem of helicopter noise. A discussion of the reasonableness of the extrapolations and of the applicable exposure durations will be presented later in this section, after some examination of the meaning of the curves in Figure 6.

Figure 6 shows that one percent of people who are exposed to 110 dBA for 8 hours per day for 40 years suffer an NIPTS of more than 37 dB, and 0.2 percent suffer more than 37 dB NIPTS for exposure to 108 dBA for that same time. The line in Figure 6 labelled "distribution of hearing level of non-exposed population of 60 year-olds" shows that it is not relevant to consider NIPTS for 40-year exposures to noise at less than 108 dBA if 37 dBA NIPTS is the protection criterion; normal ageing causes the small fraction of the population which is to be protected at that level to suffer a 37 dB loss of hearing, even if they are not exposed to unusually loud noise throughout their working life.

The extrapolations shown in Figure 6 are reasonable, since the resulting curve for 37 dB NIPTS shows that essentially 100 percent of the population will lose the ability to carry on conversation effectively if people are exposed for a working lifetime to noise at a level equalling the threshold of pain. It seems likely that evolutionary processes have supplied the human organism with a pain-avoidance mechanism which encourages people to avoid sound which can destroy their ability to converse with other people.

Figures 5 and 6 do not provide information about the effects of exposure for less than 8 hours per day and/or for less than 40 years. An "equal energy

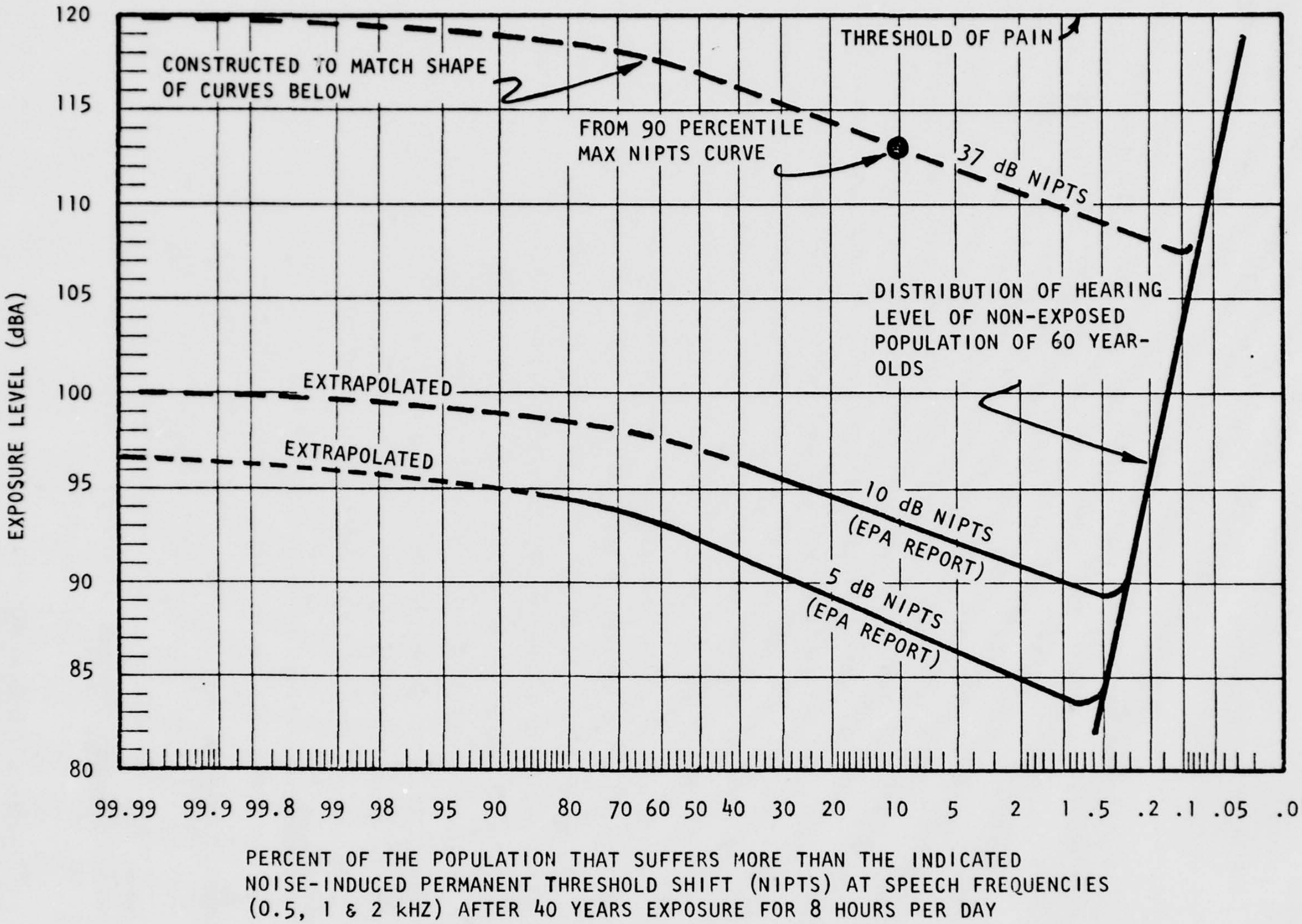


FIGURE 6. LIMITS OF NOISE EXPOSURE REQUIRED VS. DESIRED PERCENT OF POPULATION TO BE PROTECTED

rule"[9] allows an increase of noise levels by 3 dBA for each halving of exposure time. (Some investigators use a "five-dB-per doubling rule" for "speech frequencies.") That rule would allow raising the 37 dB NIPTS curve in Figure 6 by 3 dBA if exposures were limited to 4 hours per day. Limiting exposures to 10 years also would allow raising the curve some, but differences between hearing loss after ten years exposure and after 40 years exposure are small.[11] However, there is little information about rates of hearing loss near the threshold of pain. Since it is likely that hearing loss is disproportionately rapid for sound levels in the neighborhood of the threshold of pain, a cautious approach requires assuming that the curve for 37 dB NIPTS in Figure 6 applies to exposures of less than 8 hours per day for less than 40 years.

There are no extrapolations involved in applying Figure 6 to the U. S. Army's criterion for hearing protection.[14] That portion of the 5 dB NIPTS curve that is below 95 dBA is based on measurements. That curve shows that 2 percent of people routinely exposed for 8 hours per day to sound levels equal to the maximum allowed by the U. S. Army (85 dBA) will suffer a 5 dB NIPTS after 40 years of exposure. Helicopter pilots normally will not be exposed to helicopter noise for 40 years, but there is little difference between hearing losses after 10 years of exposure and hearing losses after 40 years of exposure.[11] As far as hearing loss at "speech frequencies" is concerned, it does no good to lower the maximum allowed sound level below 85 dBA, because the 1/2 percent of the population that is to be protected by going to a lower level cannot hear sounds at that level at age 60 even if they have not been exposed to loud noise during their working years. OSHA and Army regulations allow a 5 dBA increase in sound level for each halving of daily exposure, up to a maximum sound level of 115 dBA for OSHA and 110 dBA for the Army.

3.4 ARTICULATION INDEX

Articulation Index (AI) is a weighted fraction representing, for a given speech channel and noise condition, the effective proportion of the normal speech signal that is available to a listener for conveying speech intelligibility. AI is computed from acoustical estimates or measurements of the speech spectrum and of the effective masking spectrum of any noise which may be present along with the speech at the ear of a listener.

Articulation Index values were calculated for the test conditions described in this report by means of a FORTRAN IV computer program which was executed either on a CDC 6600 electronic computer or in modified form on a peripheral computer associated with a Hewlett-Packard 5451A Fourier Analyzer. The logic of the computer program is based on an American National Standards Institute Standard (ANSI S3.5).[19] The program is described and listed in Appendix D.

The sound levels generated by electronic communications of speech in helicopters are sufficiently high that ANSI S3.5 rules out the use of octave-band sound pressure levels in the calculation of AI. For high sound levels, the ANSI standard requires the use of a 20-band method which involves the use of spectrum levels of sound. The 20-band method is based upon measurements or estimates of the spectrum level of the speech and noise present in each of 20 contiguous frequency bands. Those bands are defined in such a way that in a quiet background the speech components within each band contribute equally to speech intelligibility when the spectrum level of the speech peak at the mid-frequency of each band exceeds the threshold of audibility at that frequency by 30 decibels or more.

3.5 INTELLIGIBILITY

The intelligibility of speech depends on the extent to which extraneous sounds distract a listener's attention from the speech of interest. Figure 7 shows a curve which is useful for determining the intelligibility of speech in the presence of noise. That curve displays intelligibility as a function of Articulation Index.

The relationship between intelligibility and AI indicated by the curve in Figure 7 is approximate. There is a point beyond which speech levels cannot be increased to compensate for increased noise levels. Attempts to generate very high voice levels generally lead to distortions of speech which cause decreased intelligibility, whether the high voice levels are generated by an increased vocal effort by a person or by increasing the gain of an electronic amplifier. Frequency distortion (transmission of a signal with unequal gain as a function of frequency) usually affects intelligibility of speech.[19] Clipping to limit the dynamic range of speech signals introduces distortion and harmonics which degrade the intelligibility of speech signals.[20,21] Figure 7 is not precisely applicable to cases of amplitude and frequency distortion. Even if no such distortion occurs, the precise relationship between intelligibility and AI depends upon the nature of the transmitted message and upon the skill of talkers and listeners.

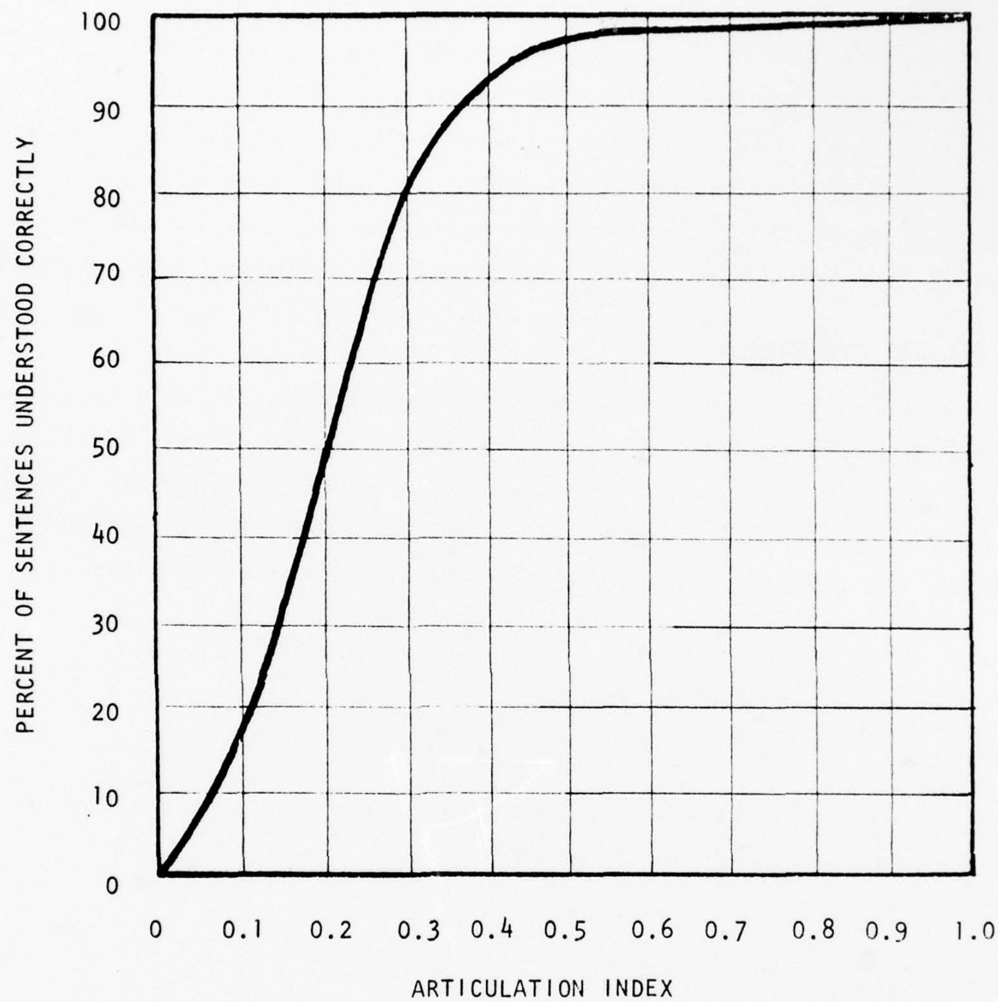


FIGURE 7. INTELLIGIBILITY OF SPOKEN SENTENCES VERSUS ARTICULATION INDEX (JASA, 19, 1947)

Gasaway[22] listed numerous references which show that articulation index probably is the best method for predicting approximate speech intelligibility for electrical communication systems. He specifically mentioned a reference[23] which shows that the 20 band method for calculating values for the articulation index is the most accurate method for predicting speech intelligibility in high-level noise. Gasaway[24] also noted an influence on intelligibility which is not described by calculations of articulation index -- there are acoustic features of voice communications in aircraft that may enhance the intelligibility of speech, such as the emphasis of plosives by a lip-position microphone.

3.6 DECIBEL AVERAGING

The composite noise levels and earcup attenuations in this report were obtained by averaging the dB, dB SPL, or dBA values of several individual measurements. If sound pressures or sound powers were averaged instead, the averages would be different. For example, if the values of 94 dB SPL and 100 dB SPL were averaged, the results would be as follows (reconverted to dB SPL).

Decibel Average:	97 dB SPL
Sound Pressure Average:	97.52 dB SPL
Sound Power Average:	97.98 dB SPL

Since earcup attenuation is the difference of two averages, the influence of the averaging method tends to be diminished.

4.0 NOISE PROFILES OF AIRCRAFT COMMUNICATION SYSTEMS

In Appendix C, there are tabulations of A-weighted noise in the communications systems for each of the 37 aircraft studied during the project. Appendix C also has untouched computer-generated plots of noise spectra for some of the aircraft types studied during the project. Noise profiles have been developed from the spectra and the A-weighted summaries. These profiles will be presented in this section.

Among the various flight conditions the plots of spectrum level vs. frequency for each aircraft type showed no significant differences between spectra, except for differences in dBA levels. Level flight is the most common flight mode and also produces an intermediate noise level; therefore, most of the remaining discussion will deal with level flight. Figures 8 through 27 represent a noise profile of 5 aircraft types. At various frequencies, most of the original spectra (See the last few pages of Appendix C) have very narrow lines which extend above the general spectrum level about 10 dB. These lines may be due to discrete frequency vibrations of transmission or engine components; however, there is not a consistent pattern of frequencies from aircraft to aircraft. These lines do not contribute significantly to the overall sound pressure level and have not been copied in the figures in this section. The fundamental rotor blade passage frequency of the helicopters is near 10 Hz. The 10 Hz effective bandwidth of the FFT filtering process is not adequate to resolve the discrete lines of pressure due to blade passage.

The frequency scale of Figures 8 through 27 is logarithmic. The curves are plotted using a constant percentage bandwidth weighting (in particular, 1/3-octave band weighting) or combined 1/3-octave band and A-weighting (see Figure 4). This is done to provide a proper visual perspective for associating the appearance of the curves with the contributions of various parts of the spectra toward the noise problem.

4.1 UH-1H IROQUOIS (HUEY)

The rank order of average ambient noise levels in the cabins of 10 UH-1H aircraft for 11 flight modes is as follows (to the nearest decibel).

	Average (dBA)
Descent	96
Descent left, right	96
Nap of earth flight	95
Climb right	94
Level flight	94
Climb	94
Climb left	93
Hover in ground effect	92
Hover at Altitude	91
Land	90 (One data sample only)

There are no data for the "take off" maneuver. A few measurements were made during maximum performance maneuvers. There is no significant difference between these levels and those during standard maneuvers.

A more detailed rank order of average noise levels for 3 representative flight modes is shown in Table 1.

Figure 8 shows spectra of noise which was measured in the cabins of the UH-1H's, and in the earcup of an SPH-4 helmet. In a previous U.S. Army project,[25] the main descrete noise sources in the UH-1A were identified as follows.

- o Main rotor 20-220 Hz
- o Tail rotor 50-500 Hz
- o Engine 100-900 Hz
- o Main transmission 600-6,000 Hz

At frequencies near and above 1000 Hz, some of the indicated levels of earcup noise are probably higher than the true levels, due to noise introduced by the data collection, recording, and analysis process. The extent and significance of this is discussed in Appendix B. However, the overall dBA levels cited in the report are not greatly affected by earcup noise at the higher frequencies.

Figure 9 suggests a noise model for the UH-1H which will be seen to be applicable to all the aircraft in this study. The model has the following components.

- o A noise spectrum in the earcup which slopes downward as frequency increases (due to earcup leakage), designated NO KEY in Figure 9.

TABLE 1 AVERAGE NOISE LEVELS AND EARCUP ATTENUATION

AIRCRAFT	FLIGHT MODE	CABIN AMBIENT	EARCUP NO KEY	EARCUP ATTENUATION *	EARCUP KEY, NO TALK	EARCUP KEY, TALK	RANGE, EARCUP KEY, TALK
UH-1H	Descent	96 dBA	86 dBA	10 dB	86 dBA	90 dBA	86-97 dBA
	Level Flight	94	84	10	86	90	86-96
	Hover at Altitude	91	80	11	83	94	89-98
OH-58A	Descent	91	85	6	85	86	84-93
	Level Flight	92	85	7	85	86	85-89
	Hover at Altitude	91	81	10	82 (3 samples)	84 (2 samples)	83-86
OV-1D	Descent	101	86	15	88	91	78-94
	Level Flight	101	87	14	88	89	80-95
AH-1S, 1Q	Descent	95	87	8	87	88	85-89
	Level Flight	95	86	8	87	88	85-90
	Hover at Altitude	92	83	9	84	-	-
CH-47C	Descent	111	93	18	93	93	92-94
	Level Flight	110	92	18	93	93	92-94
	Hover at Altitude	110	91	19	92	-	-
CH-54B	Descent	97	84	13	87	90	86-96
	Level Flight	97	85	12	89	90	86-97
	Hover at Altitude	97	89	8	-	-	-

* Difference of dBA levels in the first two columns

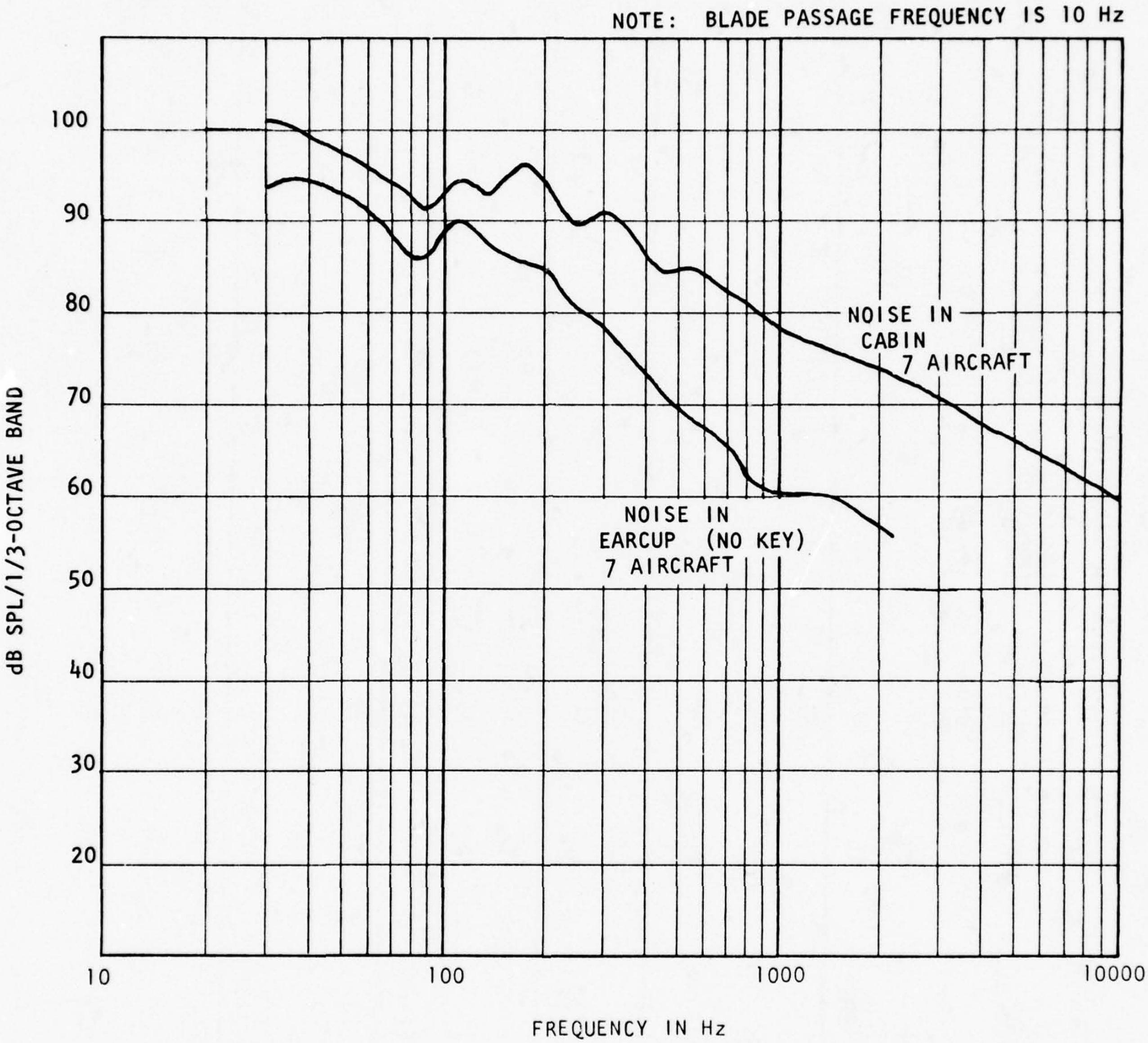


FIGURE 8 UH-1H IROQUOIS: CABIN AND EARCUP (NO KEY) NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

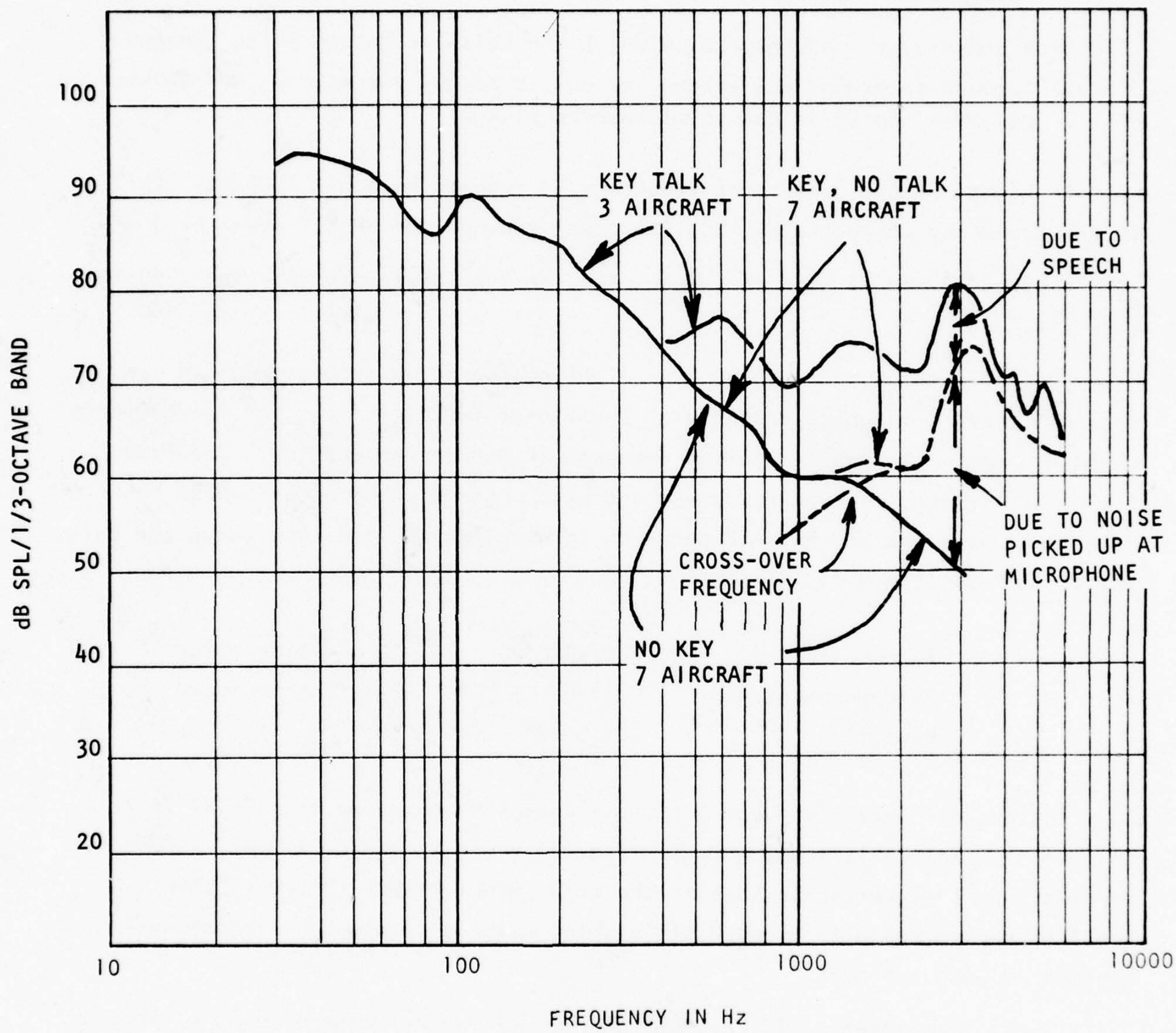


FIGURE 9 UH-1H IROQUOIS: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

- A separate noise spectrum in the earcup due to noise which is picked up at the microphone when it is keyed. This spectrum slopes upward as frequency increases, up to the upper cut-off frequency of the interphone. The peak at 3 kHz is due mostly to the earphone response.[7]
- A cross-over frequency below which the noise is due to noise leaking through or around the earcup or due to earcup vibrations, and above which the noise is due to microphone pickup.

In Figure 9, the cross-over frequency is seen to be about 1500 Hz. This is the frequency where the KEY NO TALK level exceeds the NO KEY level by 3 dB.

Figures 10 and 11 show the range of noise spectra encountered for 7 UH-1H aircraft.

Figure 12 shows the result of A-weighting the noise levels shown in Figure 9. The A-weighted curves are significant for estimating the improvements which are needed to reduce hearing damage risk and speech masking. The relative contributions of earcup leakage and microphone pick up of noise can be determined from the KEY NO TALK curve by integrating the pressure above and below the cross-over frequency, as follows.

Earcup leakage	82 dBA	72% of noise power
Microphone pickup	78 dBA	28% of noise power
Overall	83.5 dBA	

The overall level is about 2 dB less than that obtained for KEY NO TALK in Table I. The Table I values were measured using an analog filter. These results show that earcup leakage is the major problem, but that more than 4 dB of improvement will produce diminishing returns unless the microphone circuit is also improved.

Earcup improvements will be most beneficial in the three octaves at 100, 200, and 400 Hz. In the microphone circuit, if it is considered desirable to retain the peak at 3 kHz for consonant intelligibility, then the noise-cancelling performance needs to be improved in the two octaves at 2 and 4 kHz.

4.2 OH-58A KIOWA

The ambient dBA level for 12 flight modes, averaged over 6 OH-58A aircraft, is 90.4 ± 0.6 dBA. Therefore, all flight modes are equally noisy. A detailed breakdown for 3 flight conditions is shown in Table I. The

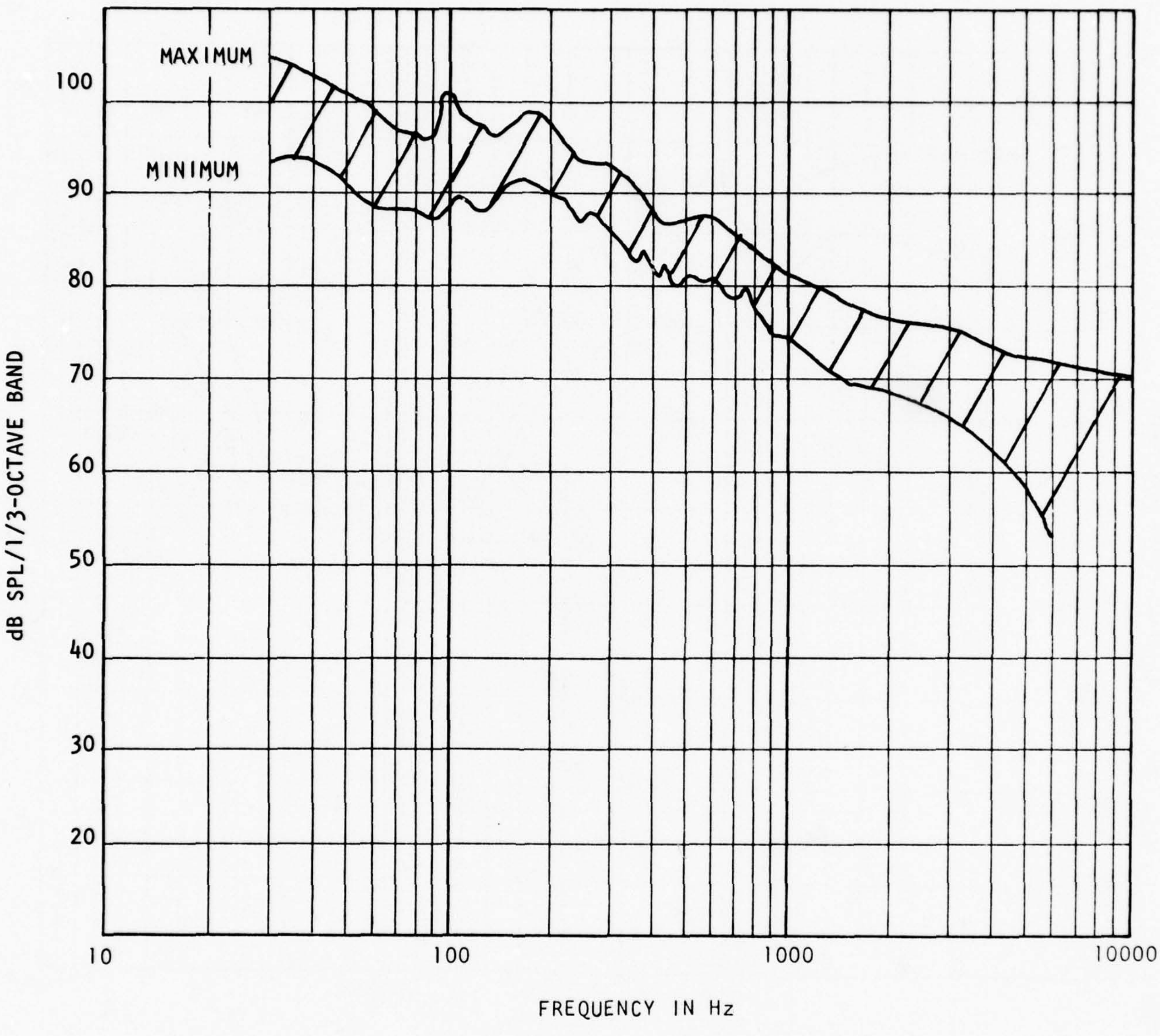


FIGURE 10 UH-1H IROQUOIS: ENVELOPE OF CABIN NOISE FOR 7 AIRCRAFT DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

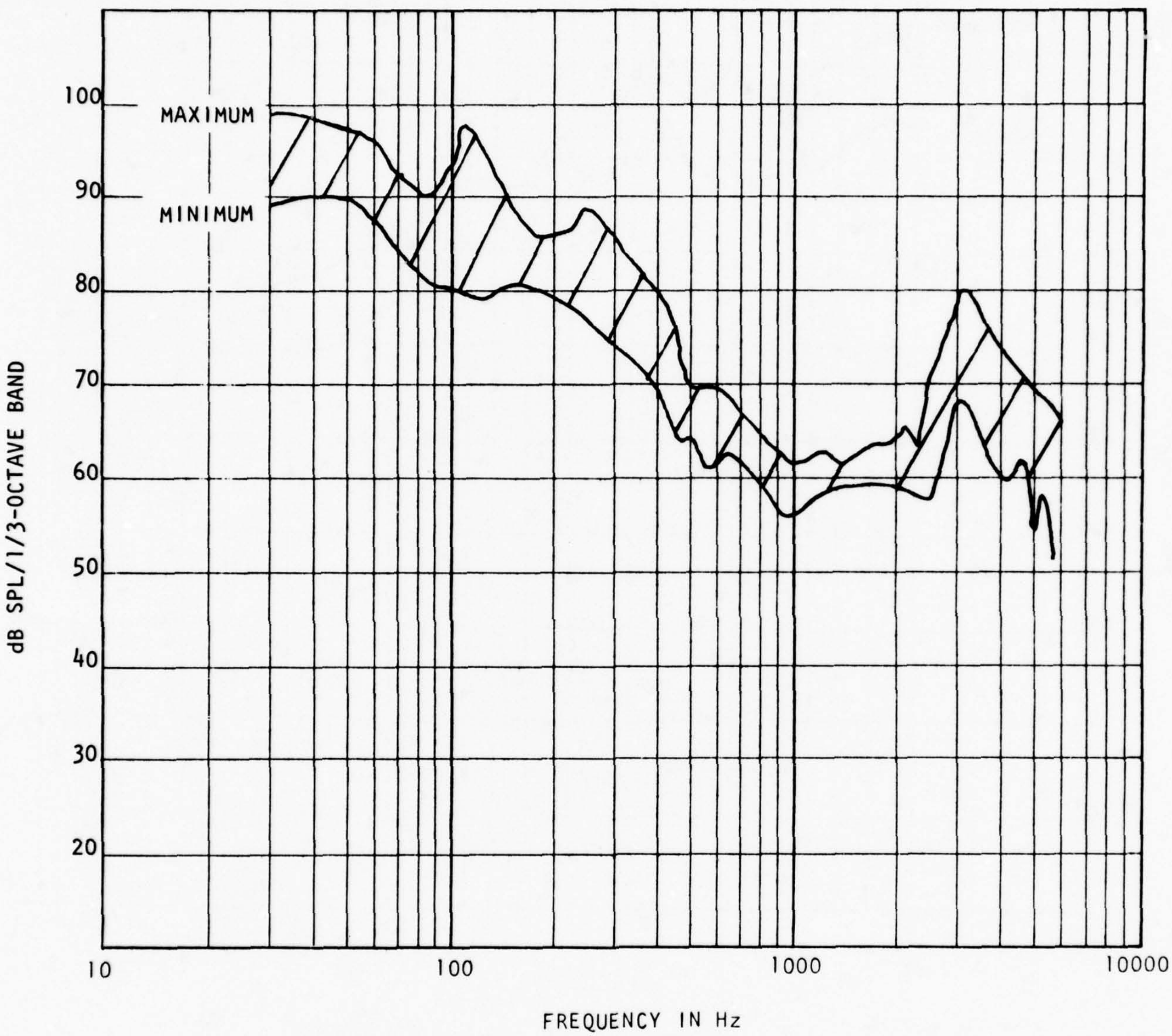


FIGURE 11 UH-1H IROQUOIS: ENVELOPE OF EARCUP (KEY, NO TALK) NOISE FOR 7 AIRCRAFT DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

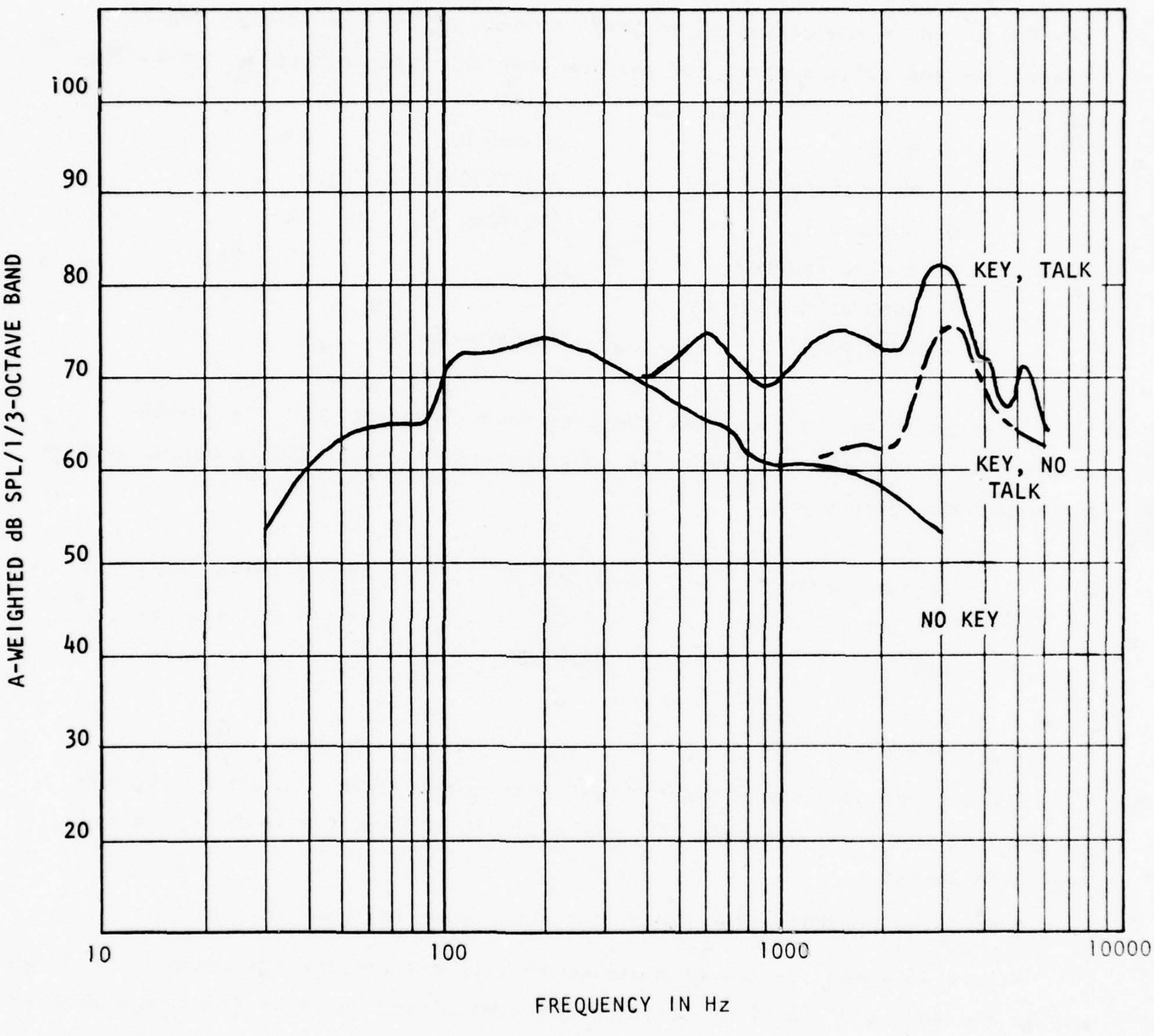


FIGURE 12 UH-1H IROQUOIS: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED, A-WEIGHTED.

CLIMB flight condition, which is representative of all flight conditions, was selected for display in Figures 13-15 because the computer-generated spectra were more complete.

Figure 13 shows spectra of noise which was measured in the cockpits of OH-58A's, and in the earcup of an SPH-4 helmet. A Bell Helicopter report identifies the noise sources for turbine-powered light helicopters as follows.[26]

o Rotors	20-600 Hz
o Main transmission	300-2400 Hz
o Accessories	600-4800 Hz
o Engine Gearbox, Compressors, and Turbines	2400-10,000 Hz

Figures 14 and 15 show that the cross-over frequency for the OH-58A is also about 1500 Hz. The relative contributions to noise due to earcup leakage and microphone pickup are

Earcup leakage	83 dBA	86% of noise power
Microphone pickup	75 dBA	14% of noise power
Overall	83.6 dBA	

4.3 OV-1D MOHAWK

The ambient dBA levels for 7 flight modes range from 100 dBA to 102 dBA. In addition there was one take-off sample at 116 dBA and two landing samples, averaging 95 dBA.

A detailed breakdown for two flight conditions is shown in Table 1.

Figure 16 shows spectra of noise which were measured in the cockpits of OV-1D's and in the earcup of an SPH-4 helmet. The predominant noise is from the propeller blade passage.

Figures 17 and 18 show that the noise cross-over frequency for the OV-1D is about 1400 Hz. The relative contributions to noise due to earcup leakage and microphone pickup are

Earcup Leakage	86 dBA	86% of Noise Power
Microphone Pickup	78 dBA	14% of Noise Power
Overall	86.6 dBA	

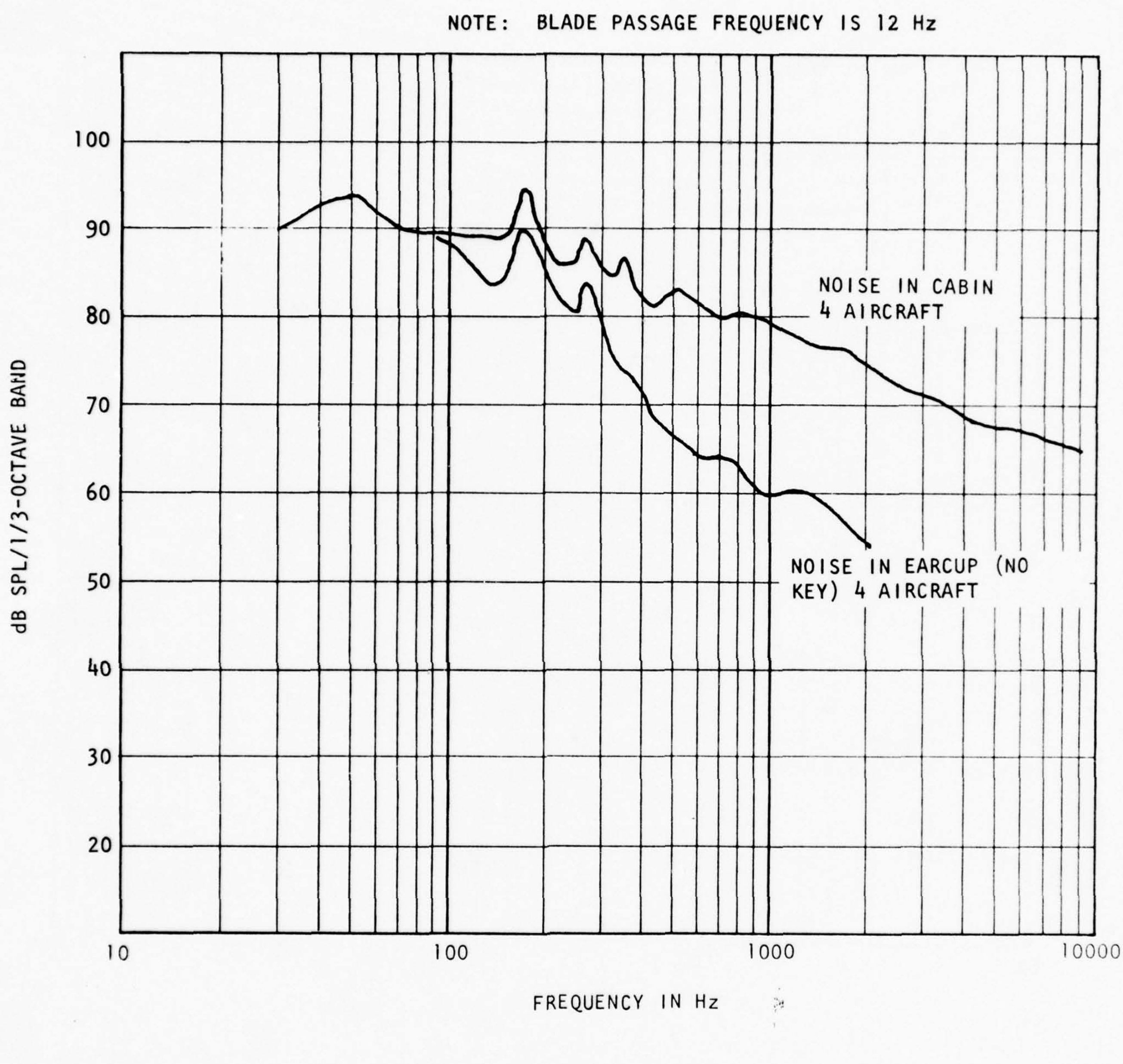


FIGURE 13. OH-58 KIOWA: CABIN AND EARCUP (NO KEY) NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED.

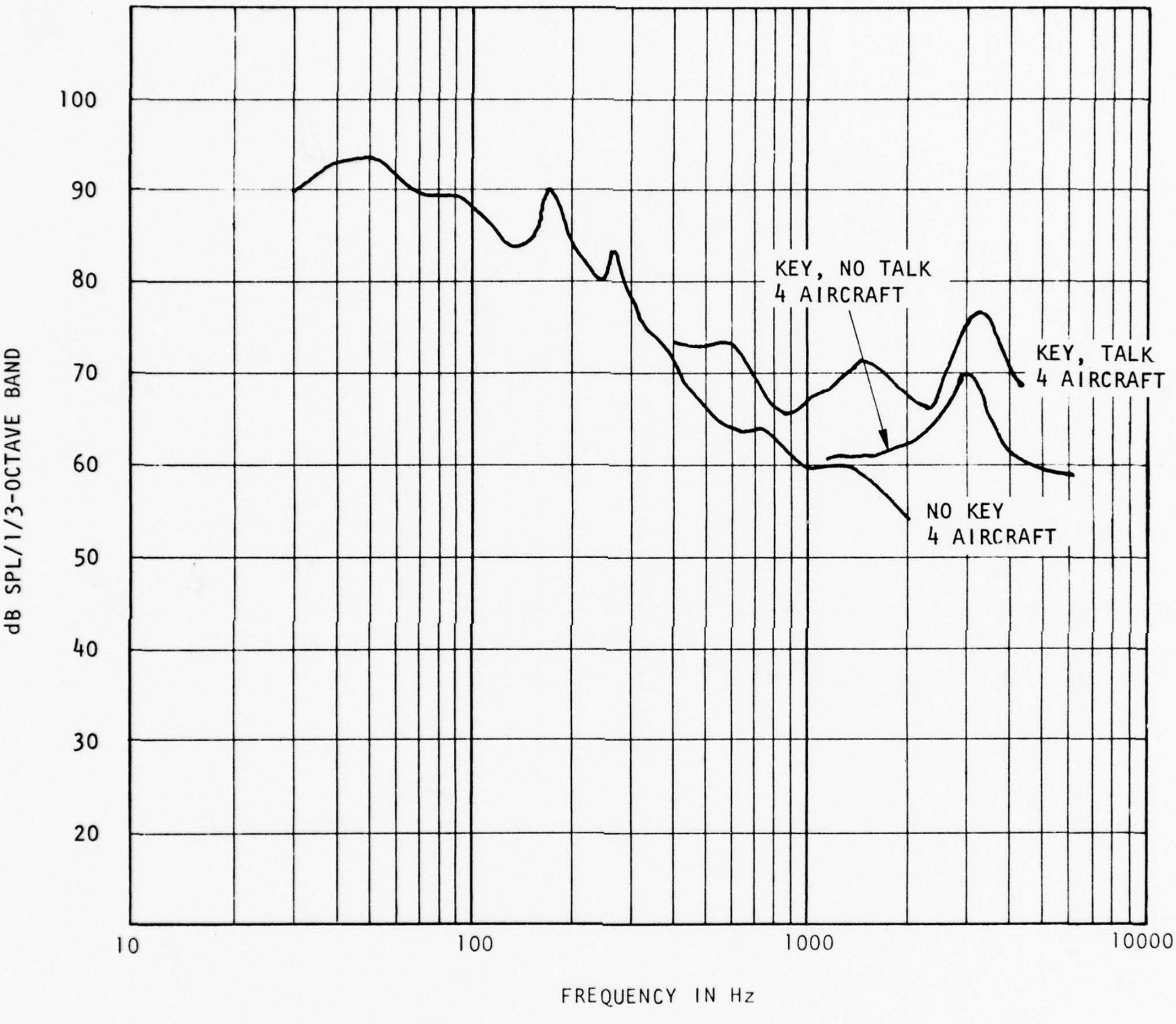


FIGURE 14 OH-58 KIOWA: EARCUP NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED.

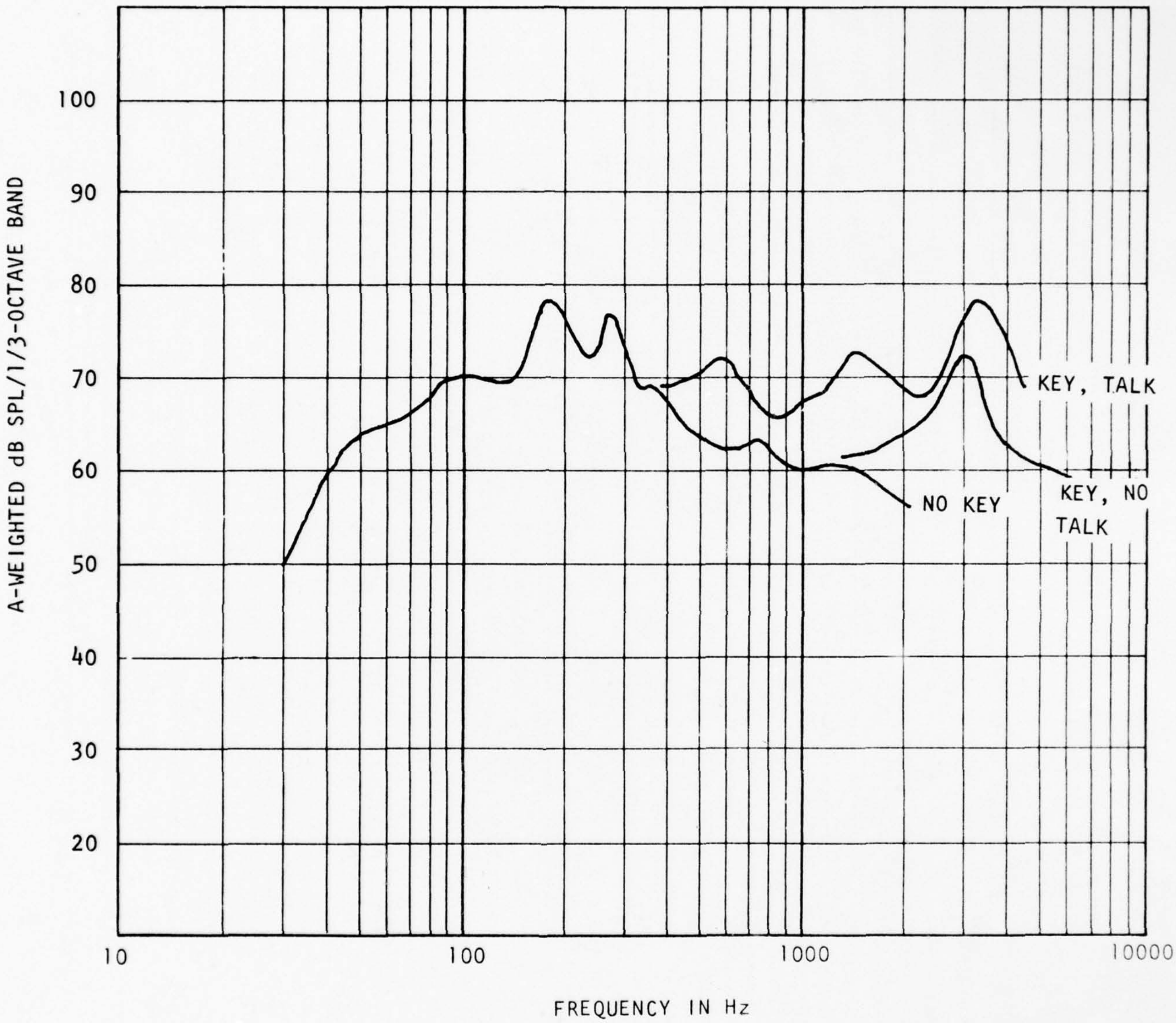


FIGURE 15 OH-58 KIOWA: EARCUP NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED, A-WEIGHTED

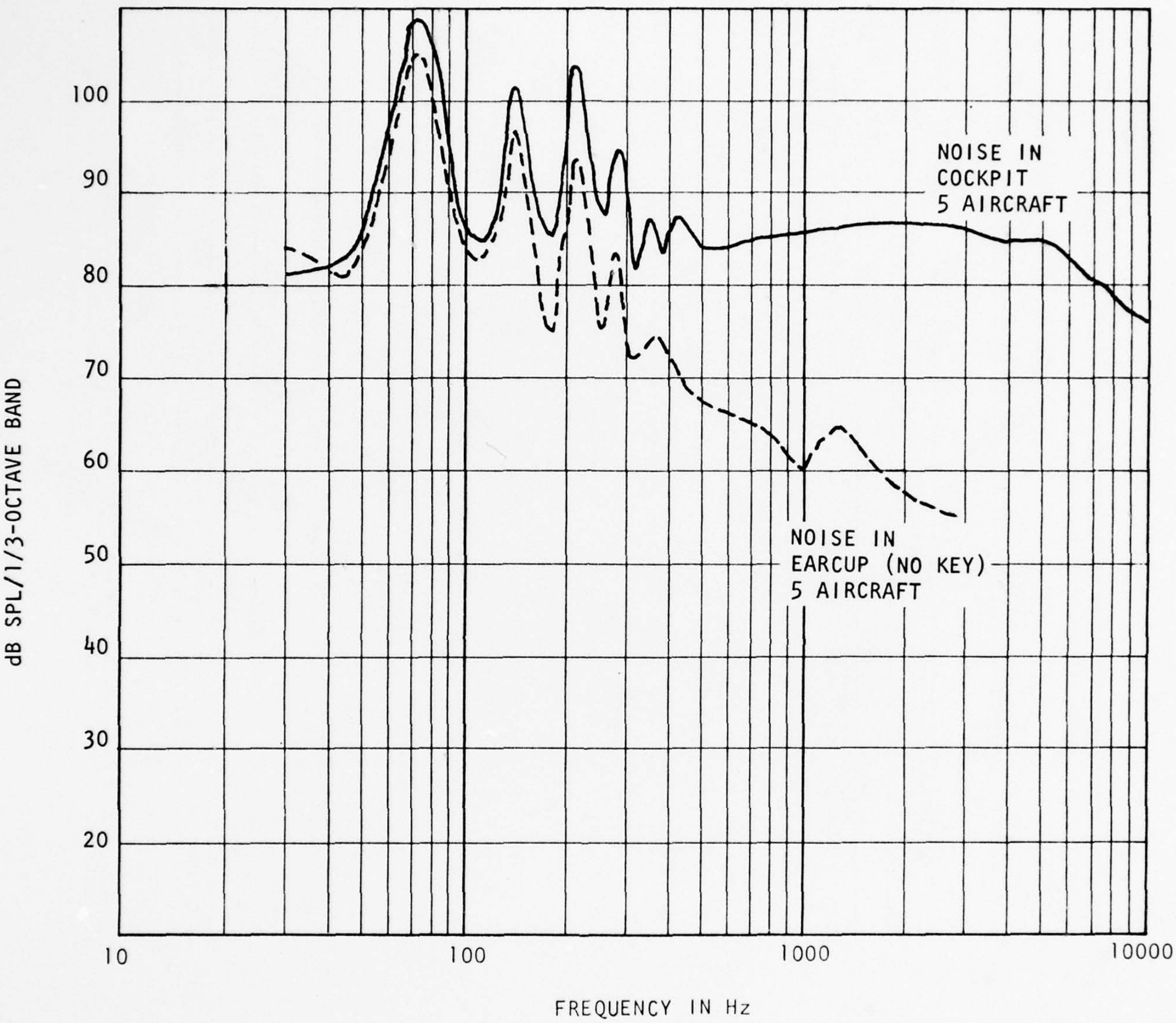


FIGURE 16 OV-1D MOHAWK: COCKPIT AND EARCUP (NO KEY) NOISE DURING LEVEL FLIGHT. 1/3 - OCTAVE WEIGHTED.

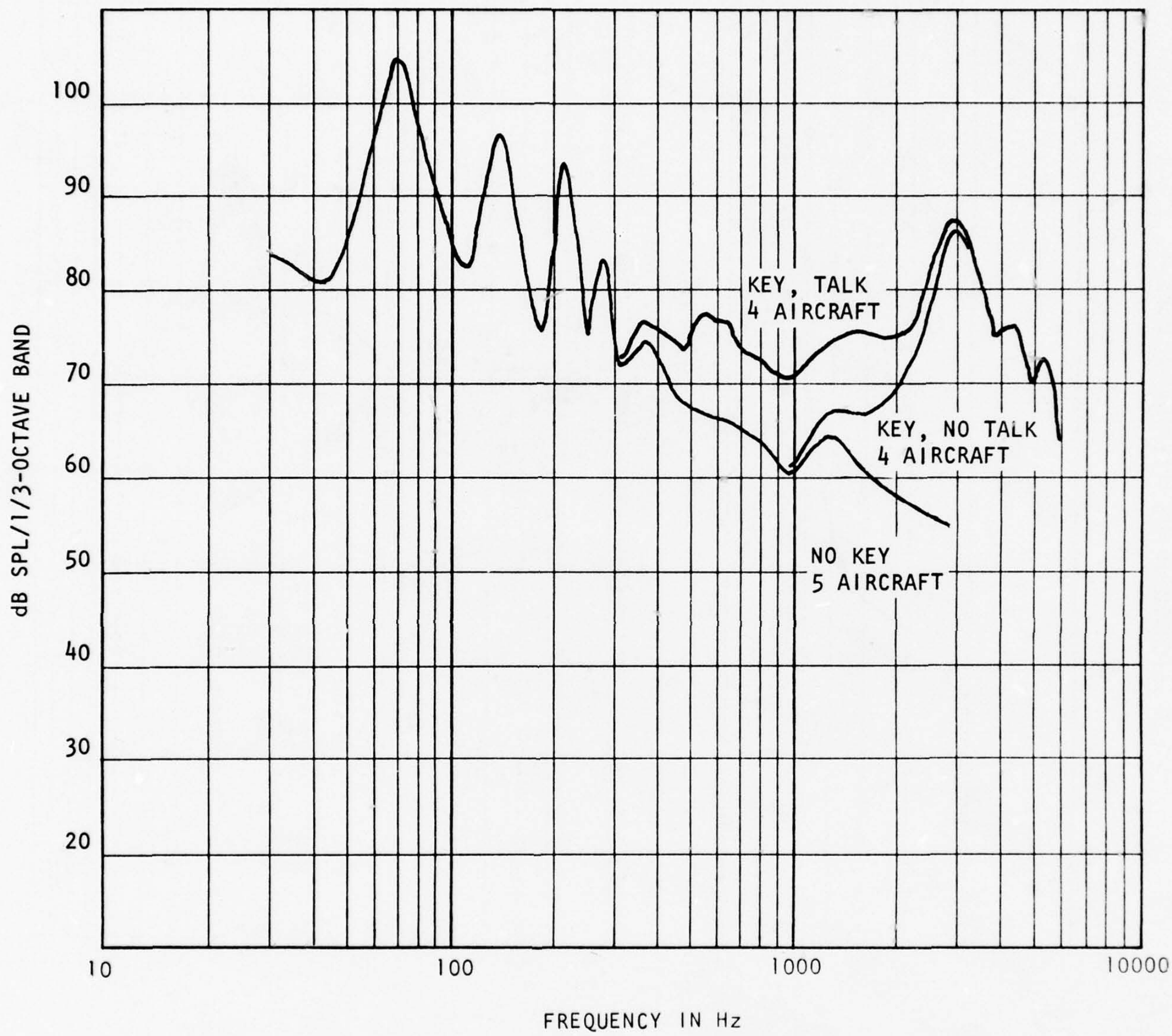


FIGURE 17 OV-1D MOHAWK: EARCUP NOISE DURING LEVEL FLIGHT. 1/3 - OCTAVE WEIGHTED.

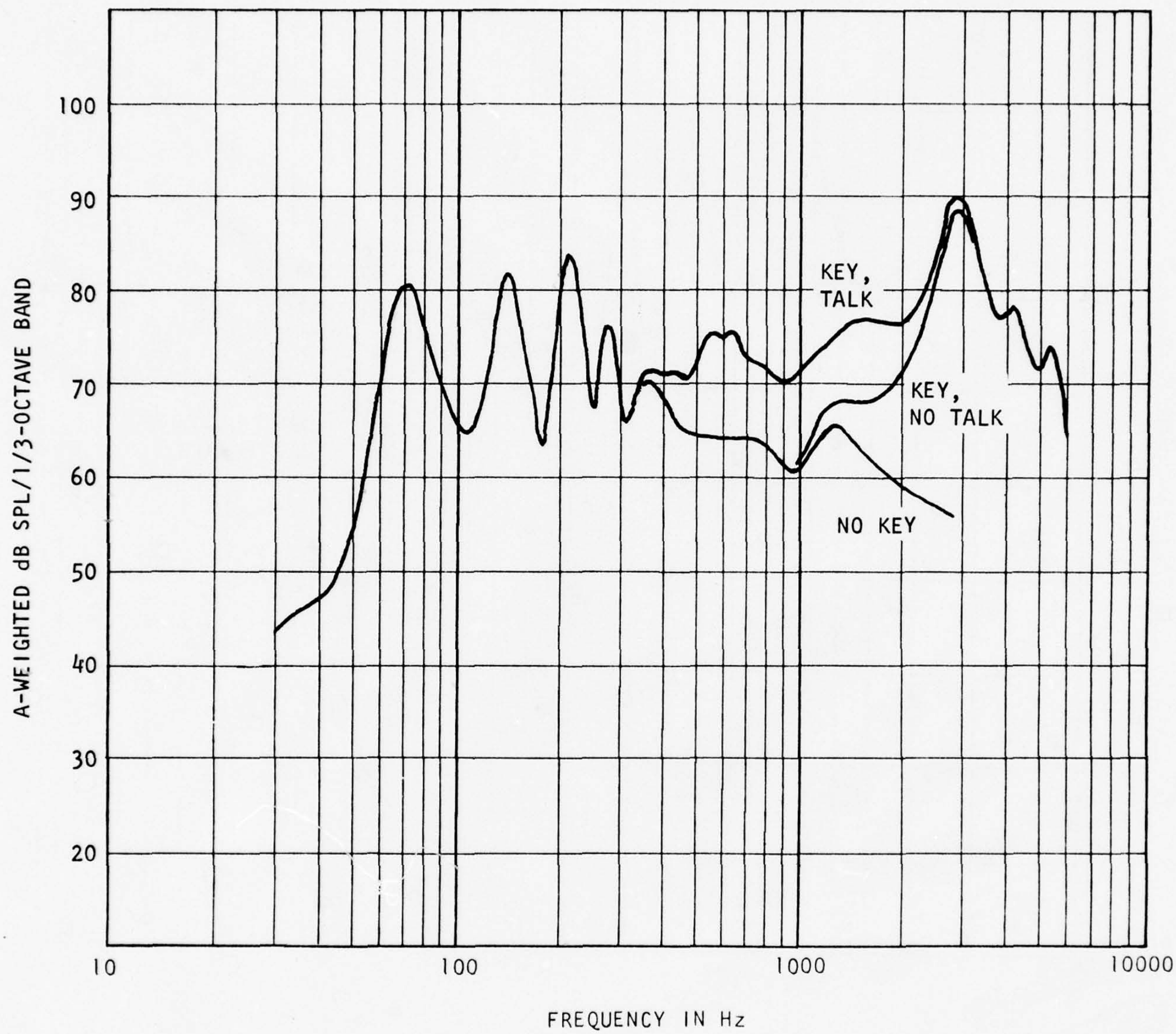


FIGURE 18. OV-1D MOHAWK: EARCUP NOISE DURING LEVEL FLIGHT. 1/3 - OCTAVE WEIGHTED, A-WEIGHTED.

4.4 AH-1S AND AH-1Q HUEYCOBRA

The data did not show any significant differences in noise levels between AH-1S and AH-1Q aircraft. The rank order of cockpit noise levels (average of 6 aircraft) for 5 flight modes is as follows (to the nearest decibel).

	Average (dBA)
Level flight	95
Descent	95
Climb	94
Hover in ground effect	93
Hover at altitude	92

A more detailed rank ordering of average noise levels for 3 representative flight modes is shown in Table 1. Figures 19-21 show the spectra of noise in the cockpit of the AH-1 and in the earcup of the SPH-4 helmet.

The noise cross-over frequency for the AH-1 is about 2200 Hz. During level flight, the relative contributions to noise due to earcup leakage and microphone pickup are

Earcup leakage	83 dBA	83% of noise power
Microphone pickup	76 dBA	17% of noise power
Overall	83.8 dBA	

4.5 CH-47C CHINOOK

The cabin noise levels (average of 3 aircraft) ranged from 110 to 111 dBA for 5 flight modes. A detailed rank ordering of average noise levels for 3 representative flight modes is shown in Table 1. Figures 22-24 show the spectra of noise in the cabin of the CH-47C and in the earcup of the SPH-4 helmet, during the CLIMB flight mode.

The noise cross-over frequency for the CH-47C is about 1800 Hz. The relative contributions to noise due to earcup leakage and microphone pickup are

Earcup leakage	89 dBA	89% of noise power
Microphone pickup	80 dBA	11% of noise power
Overall	89.5 dBA	

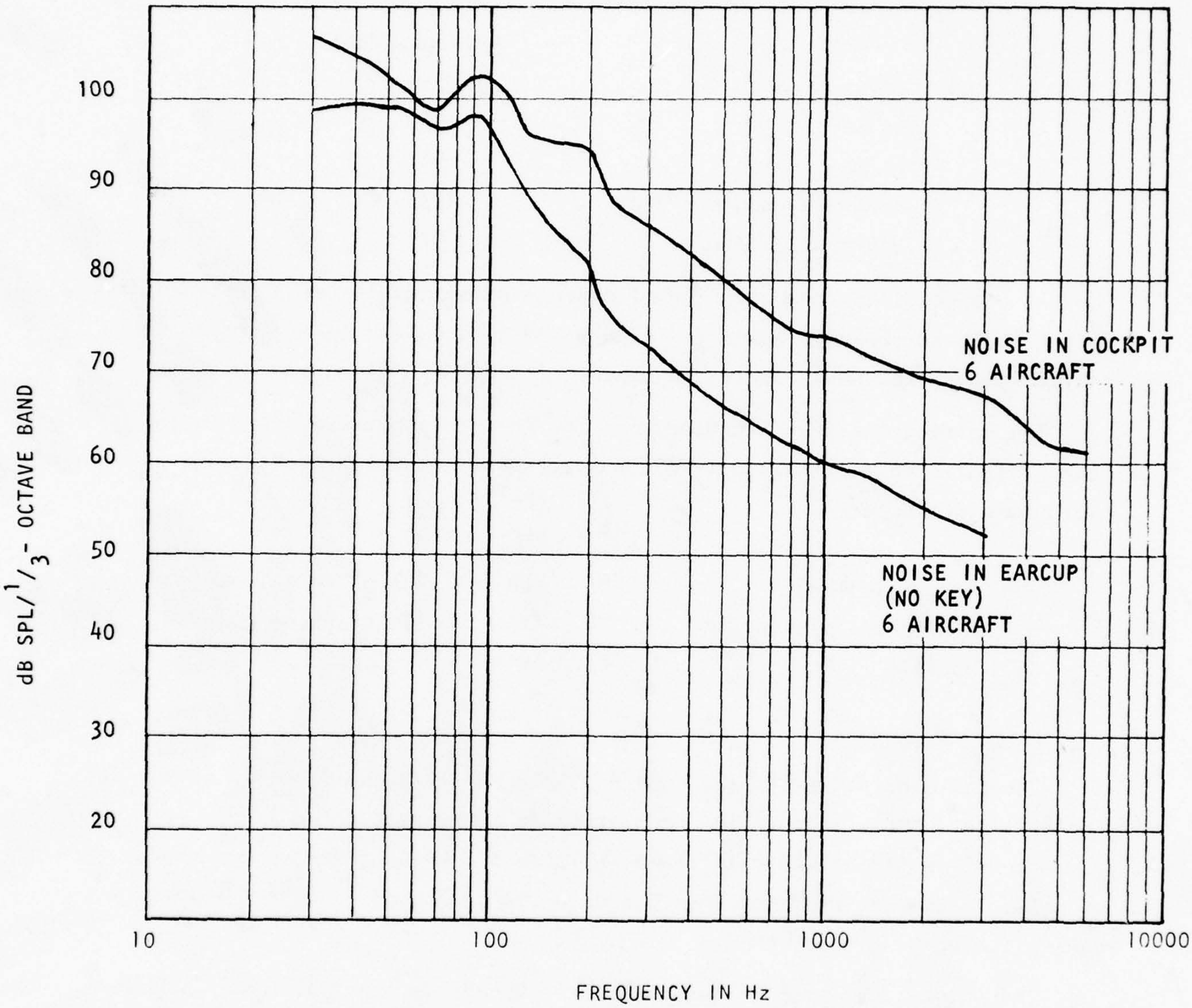


FIGURE 19 AH-1S, AH-1Q HUEYCOBRA: COCKPIT AND EARCUP (NO KEY) NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

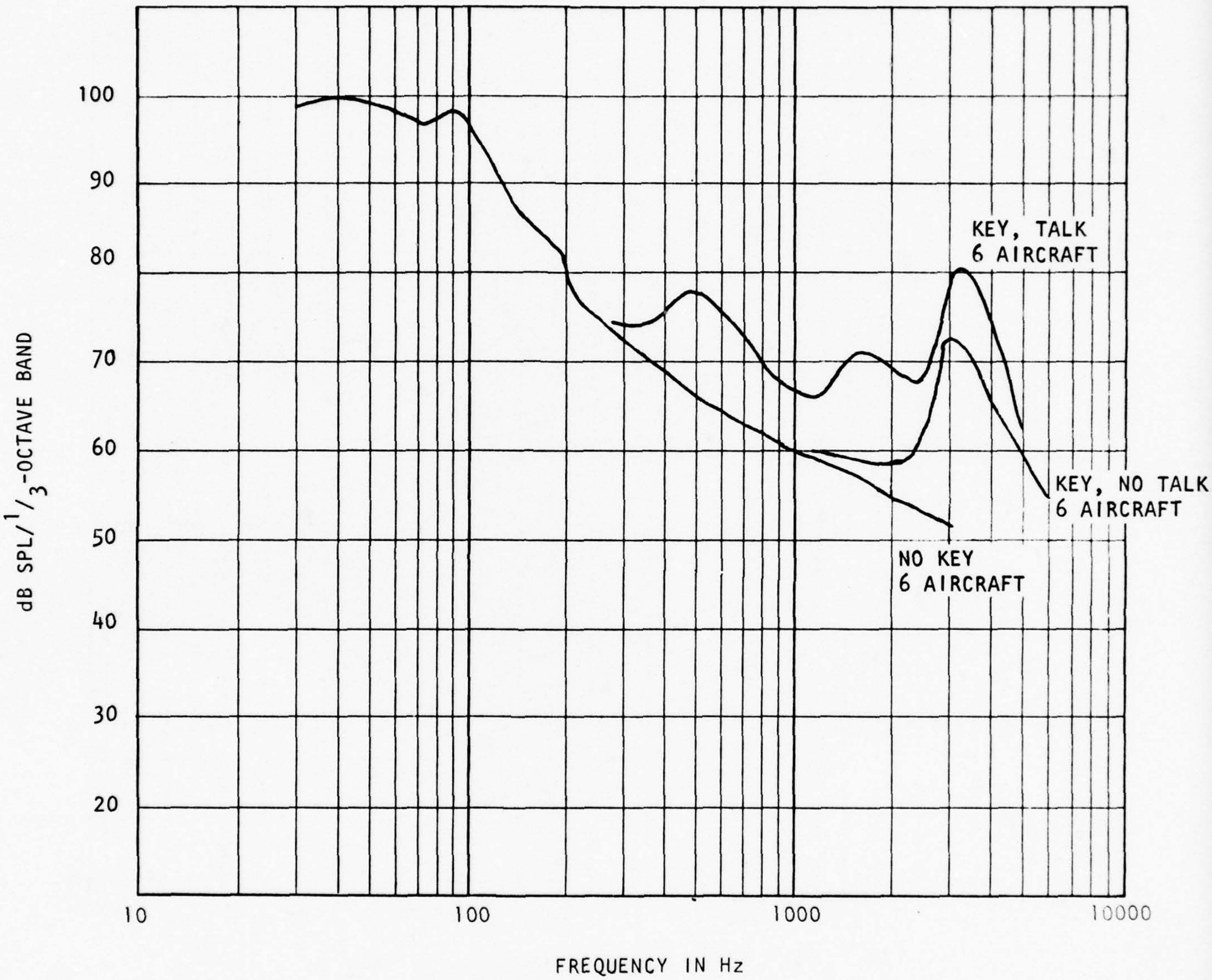


FIGURE 20 AH-1S, AH-1Q HUEYCOBRA: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

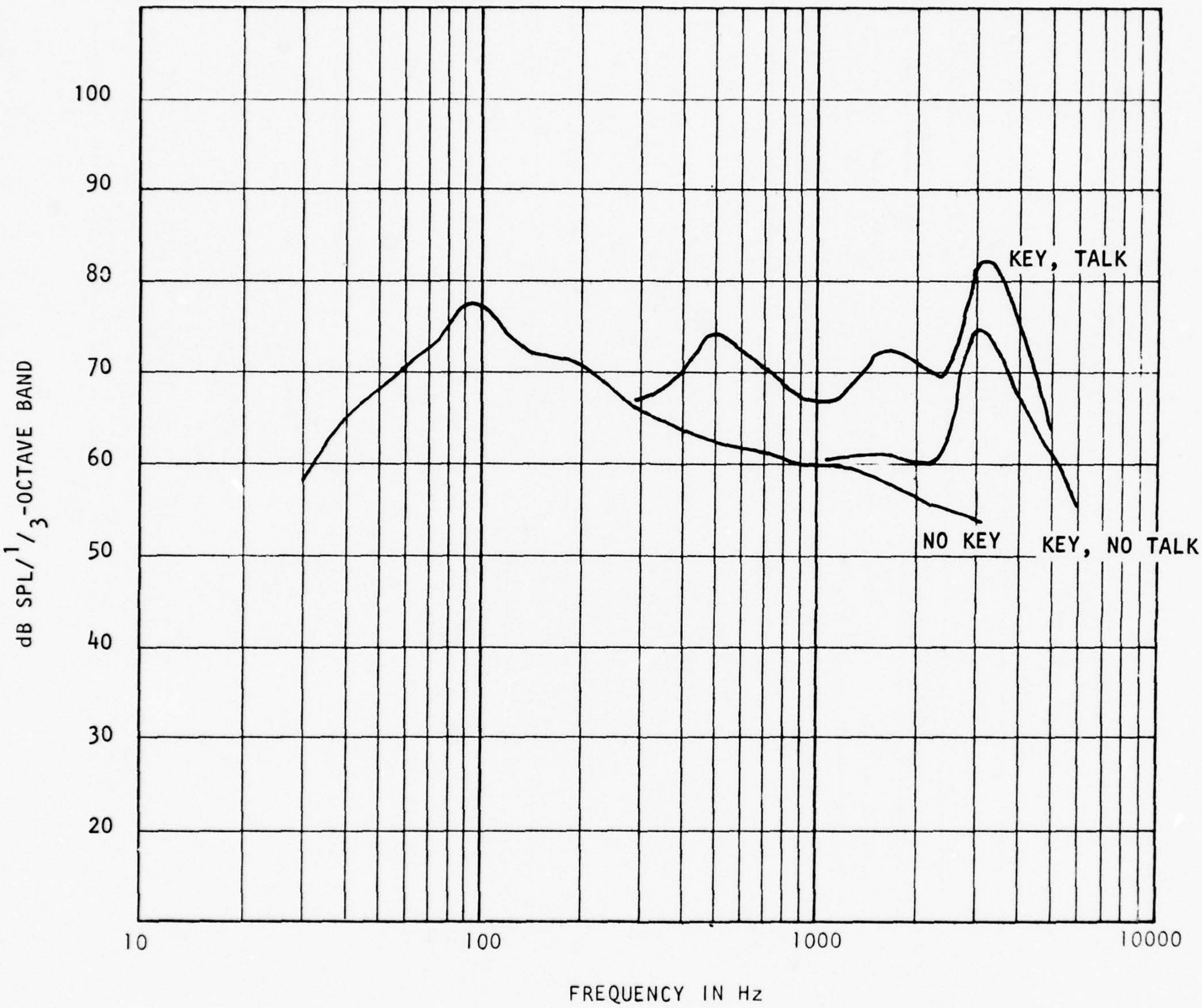


FIGURE 21 AH-1S, AH-1Q HUEYCOBRA: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED, A-WEIGHTED.

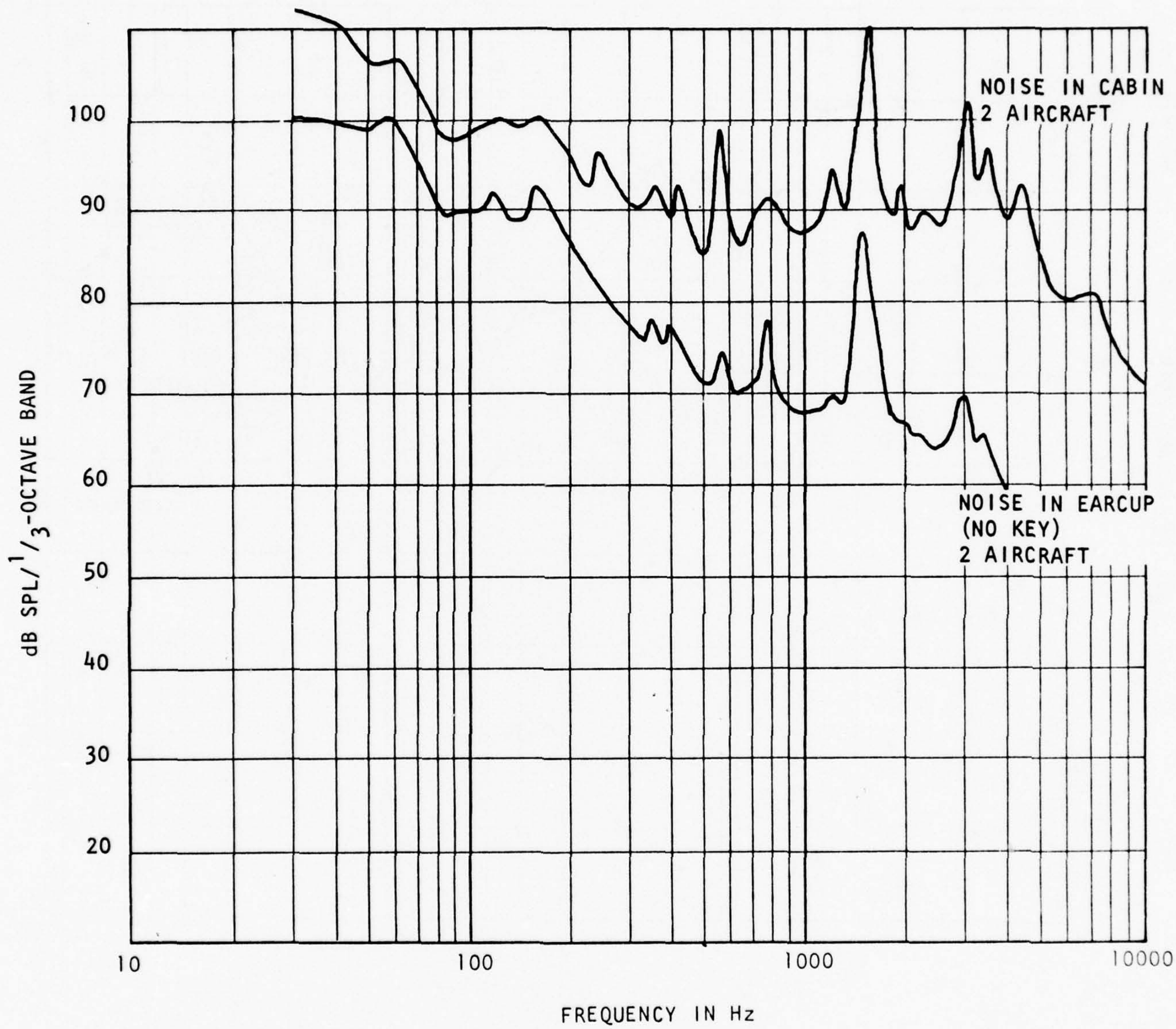


FIGURE 22 CH-47C CHINOOK: CABIN AND EARCUP (NO KEY) NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED.

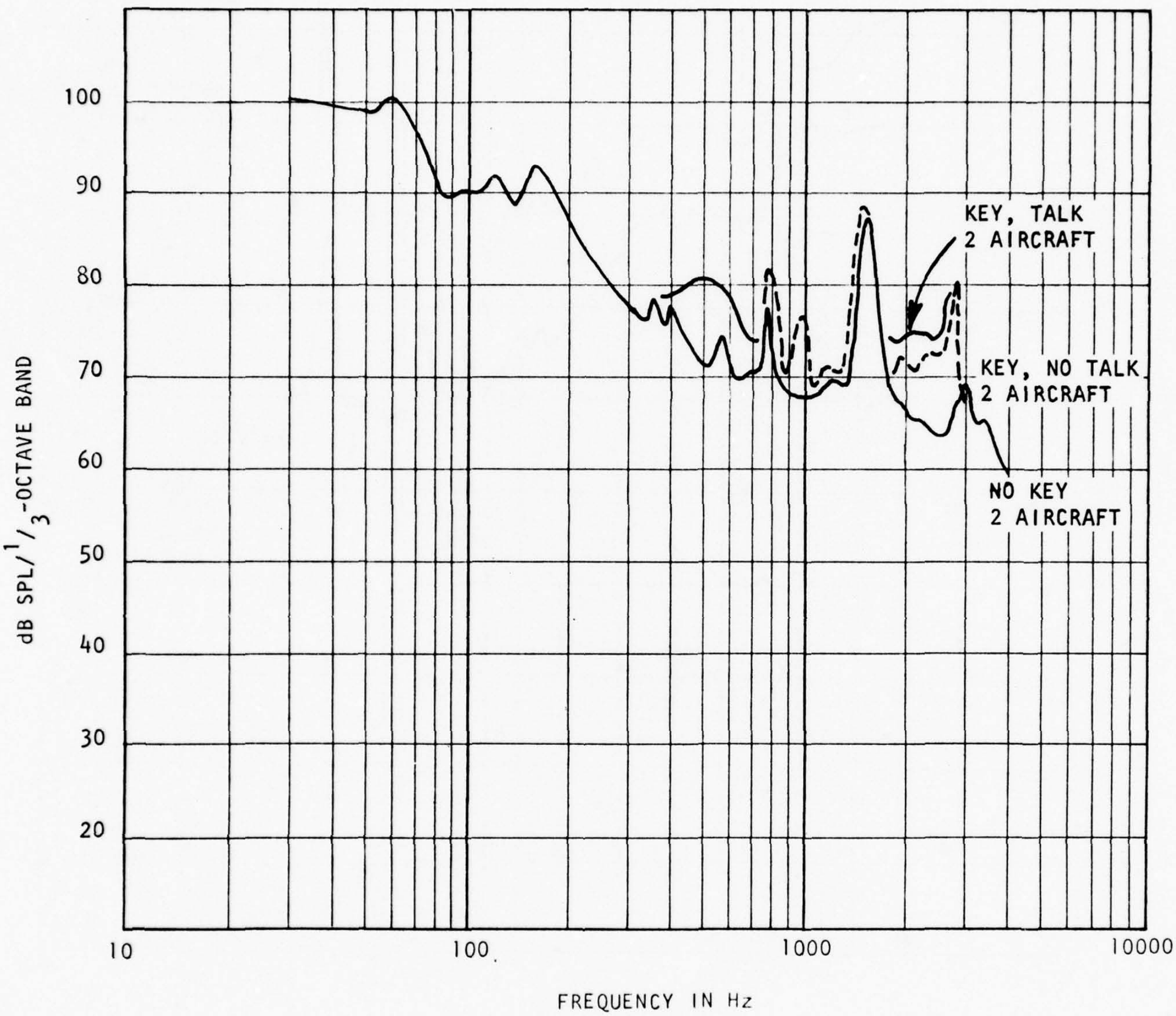


FIGURE 23 CH-47C CHINOOK: EARCUP NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED.

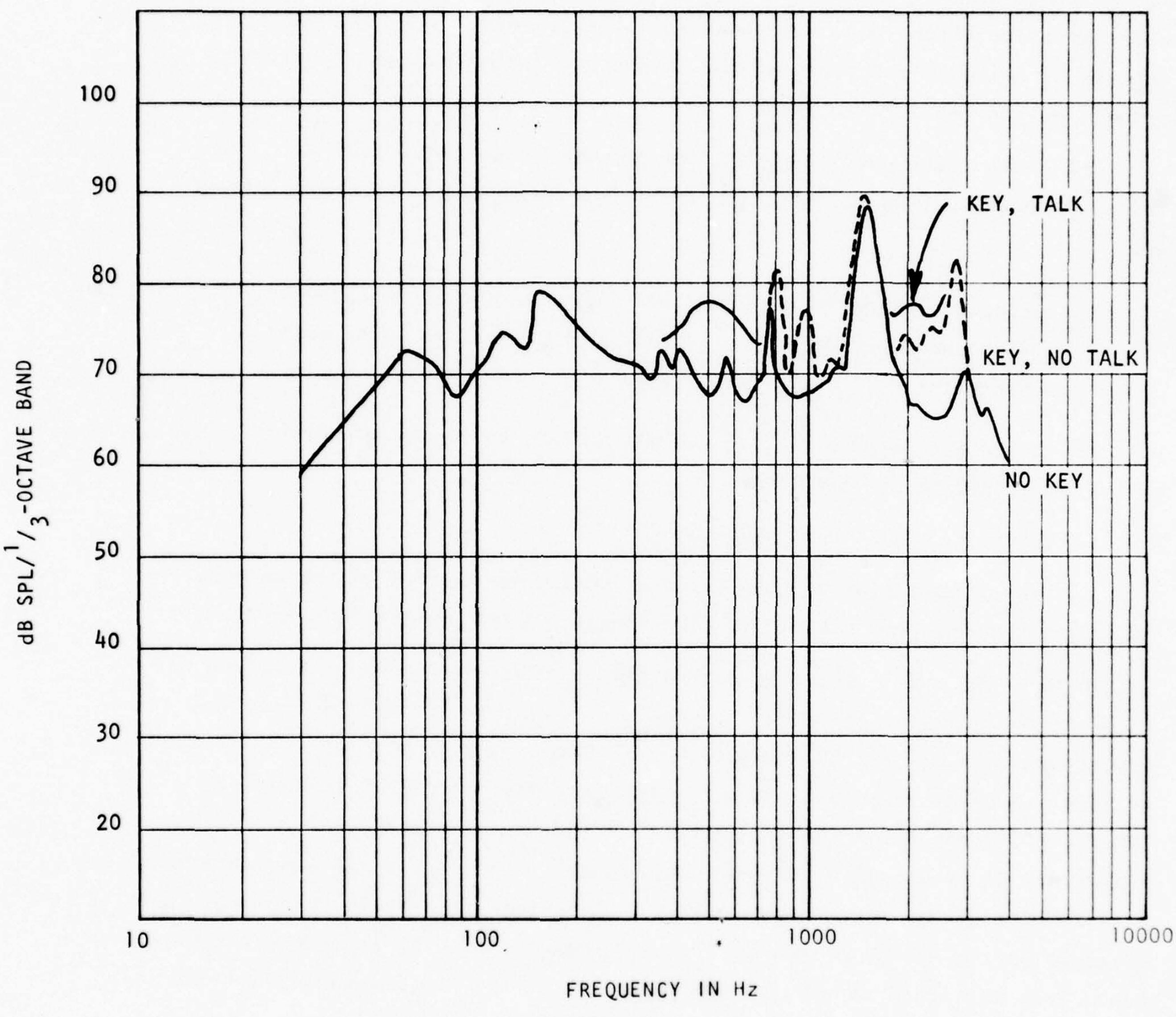


FIGURE 24 CH-47C CHINOOK: EARCUP NOISE DURING CLIMB. 1/3-OCTAVE WEIGHTED. A-WEIGHTED.

4.6 CH-54B TARHE

The cabin noise levels (average of 6 aircraft) ranged from 96 to 97 dBA for 5 flight modes. A detailed rank ordering of average noise levels for 3 representative flight modes is shown in Table 1. Figures 25-27 show the spectra of noise in the cabin of the CH-54B and in the earcup of the SPH-4 helmet, during level flight.

The noise cross-over frequency for the CH-54B is about 1800 Hz. The relative contributions to noise due to earcup leakage and microphone pickup are

Earcup leakage	85 dBA	45% of noise power
Microphone pickup	86 dBA	55% of noise power
Overall	88.6 dBA	

The relatively high pickup by the microphone is due to narrowband peaks of noise at 3200 Hz and 5000 Hz.

4.7 SPEECH LEVELS AND EARCUP ATTENUATION

Figures 28 and 29 show computer-derived speech spectra in the earcup, calculated by removing the KEY NO TALK spectrum from the KEY TALK spectrum.

Figures 30 and 31 show the earcup attenuation, derived as a function of frequency by subtracting the NO KEY spectra from the AMBIENT spectra. The lowest curve in Figures 30 and 31 is R. T. Camp's measurement of the SPH-4, as reported by Giordano and Keane.[7] The test method was USASI Standard Z24.22-1957 (Method for the Measurement of the Real Ear Attenuation of Ear Protectors at Threshold). Weinreb and Touger[27] report that real-ear-threshold measurements of ear protectors usually show better attenuation values than are obtained by the method of comparing sound pressures inside and outside the ear-cup. They attribute this to physiological factors. The heavy dashed lines in Figures 30 and 31 show a modified version of Camp's attenuation curve, showing the attenuation that might have been obtained had a comparison method been used.

The attenuation curves which are derived from measurements in the aircraft show both a deficient attenuation compared to Camp's measurement, and also a marked variability. The variability in earcup attenuation was extreme, not only from aircraft-to-aircraft, but even in successive tests in the same aircraft with the same user. Figure 32 shows earcup attenuation for 5 flight

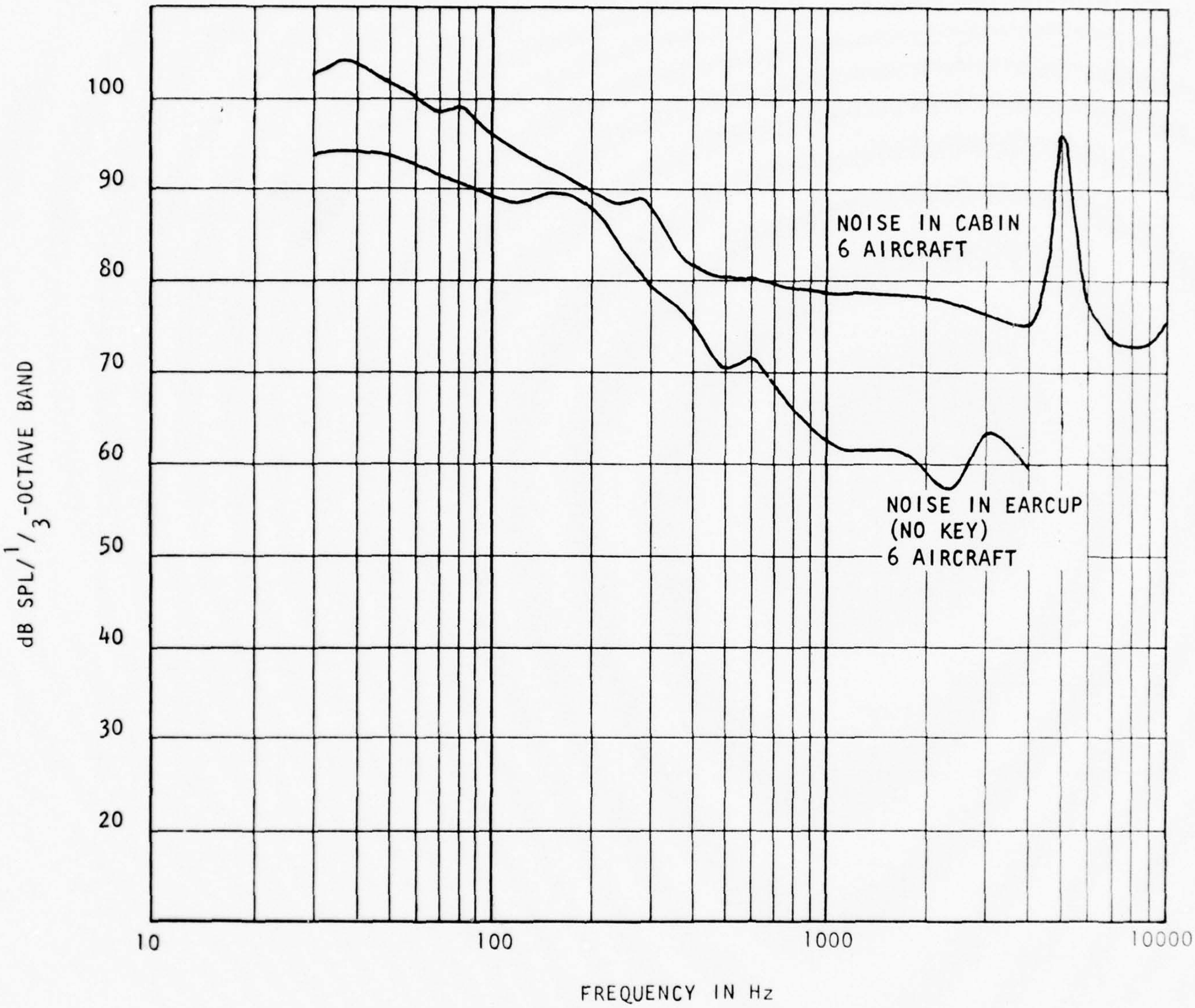


FIGURE 25 CH-54B TARHE: CABIN AND EARCUP (NO KEY) NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

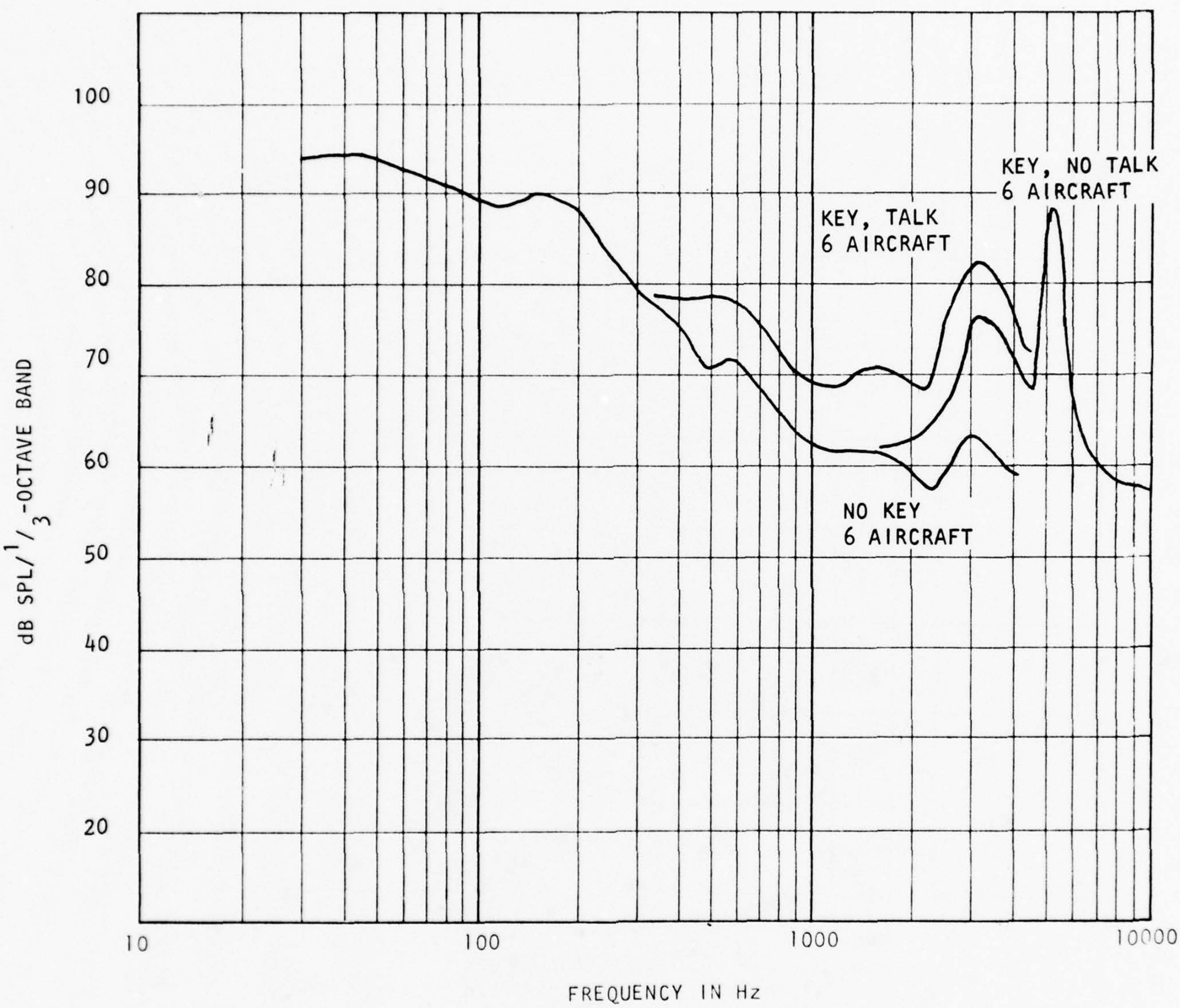


FIGURE 26 CH-54B TARHE: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED.

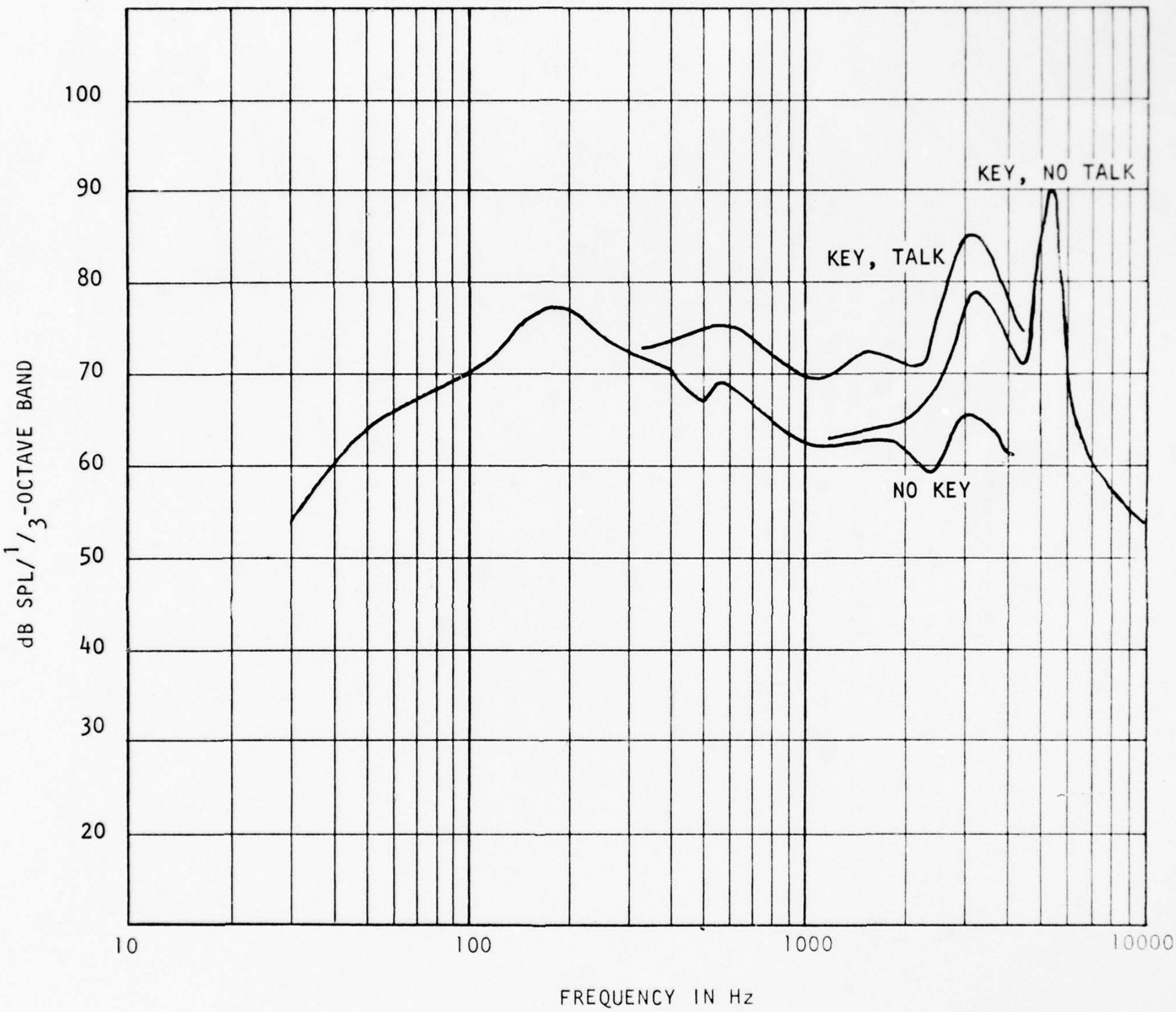


FIGURE 27 CH-54B TARHE: EARCUP NOISE DURING LEVEL FLIGHT. 1/3-OCTAVE WEIGHTED. A-WEIGHTED.

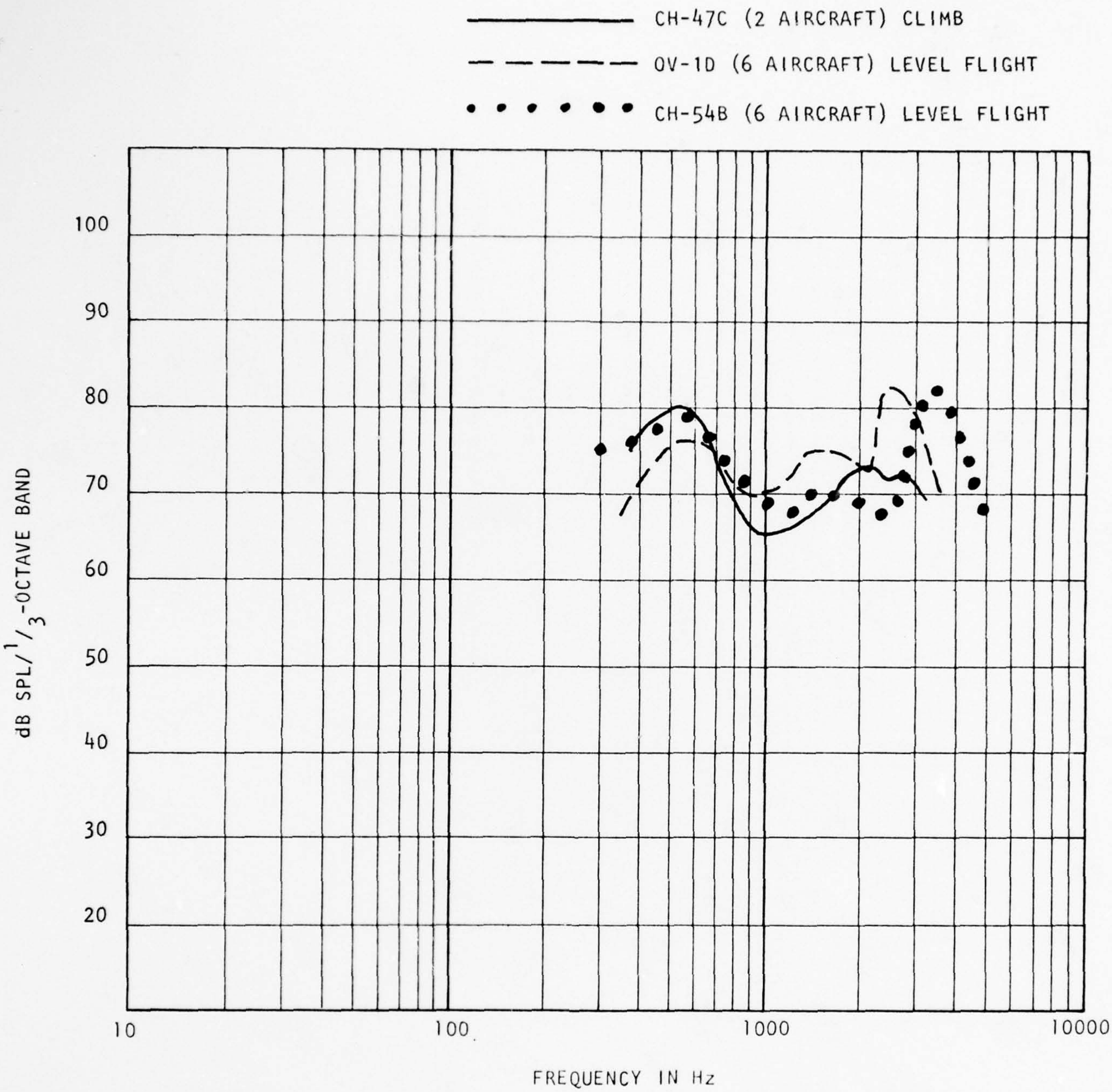


FIGURE 28. SPEECH LEVELS IN THE EARCUP IN THREE MORE NOISY TYPES OF AIRCRAFT. 1/3-OCTAVE WEIGHTED.

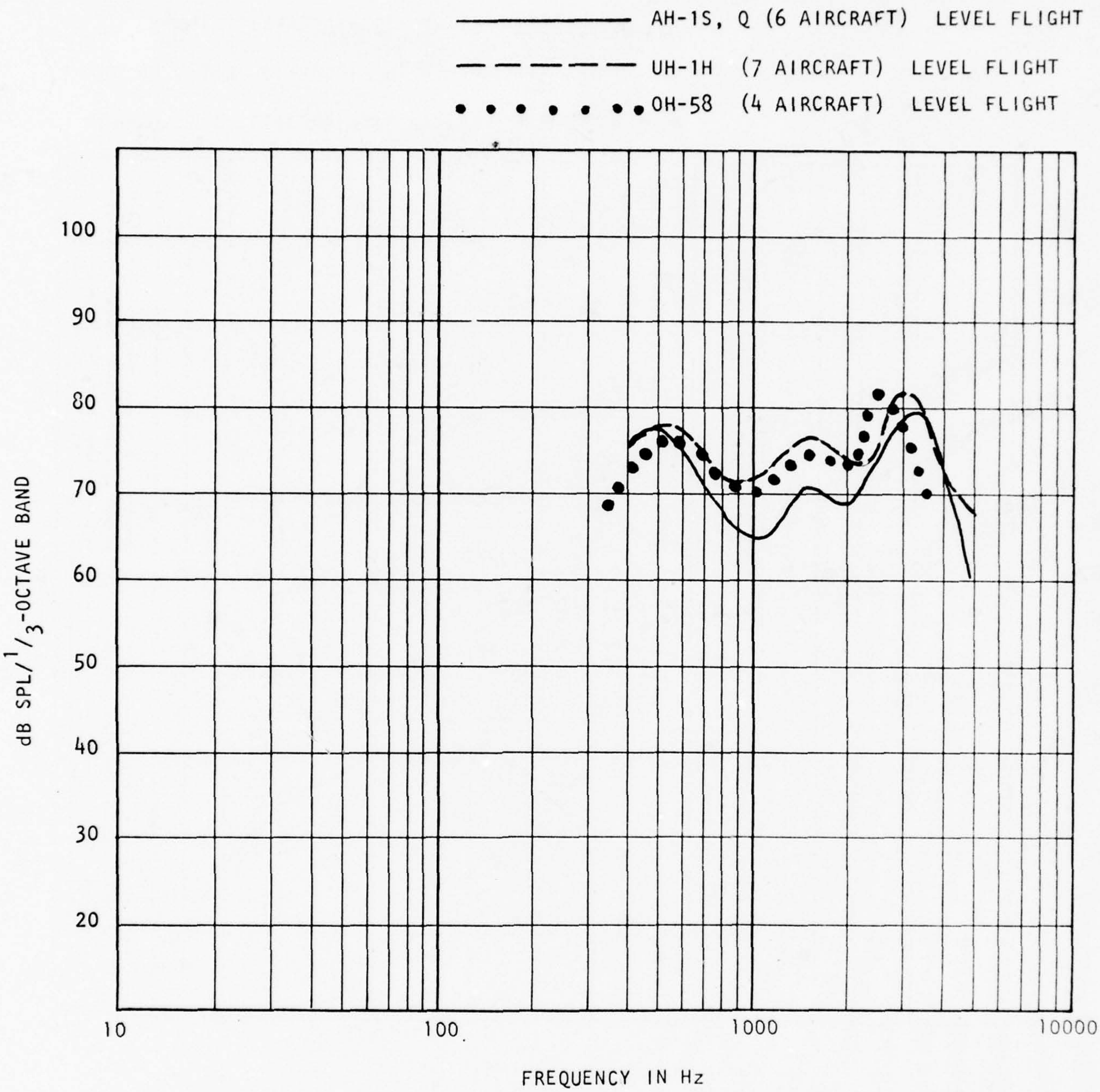


FIGURE 29. SPEECH LEVELS IN THE EARCUP IN THREE LESS NOISY TYPES OF AIRCRAFT. 1/3-OCTAVE WEIGHTED.

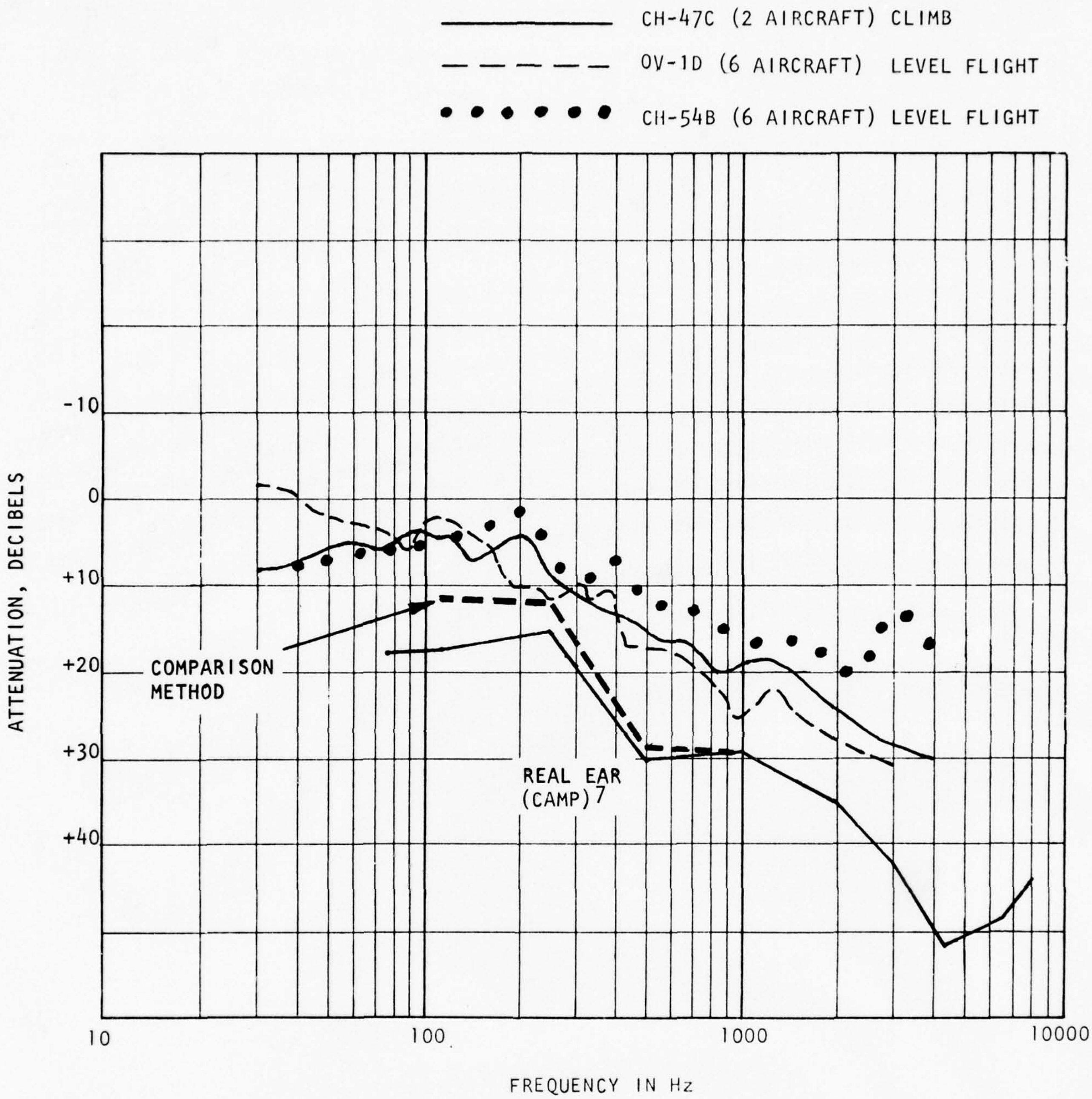


FIGURE 30 EARCUP ATTENUATION IN THREE MORE NOISY TYPES OF AIRCRAFT, SPH-4 HELMET.

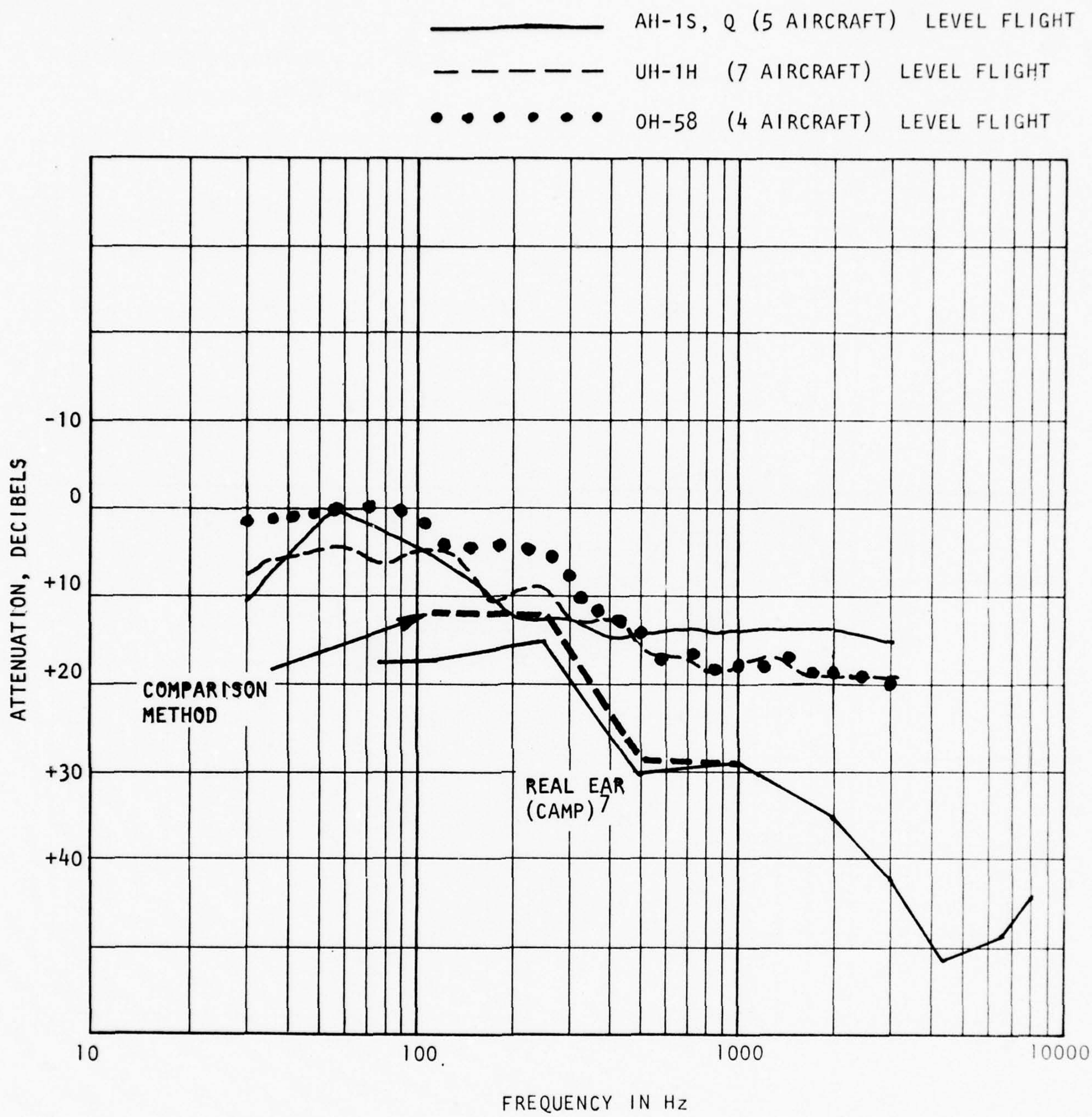


FIGURE 31 EARCUP ATTENUATION IN THREE LESS NOISY TYPES OF AIRCRAFT, SPH-4 HELMET.

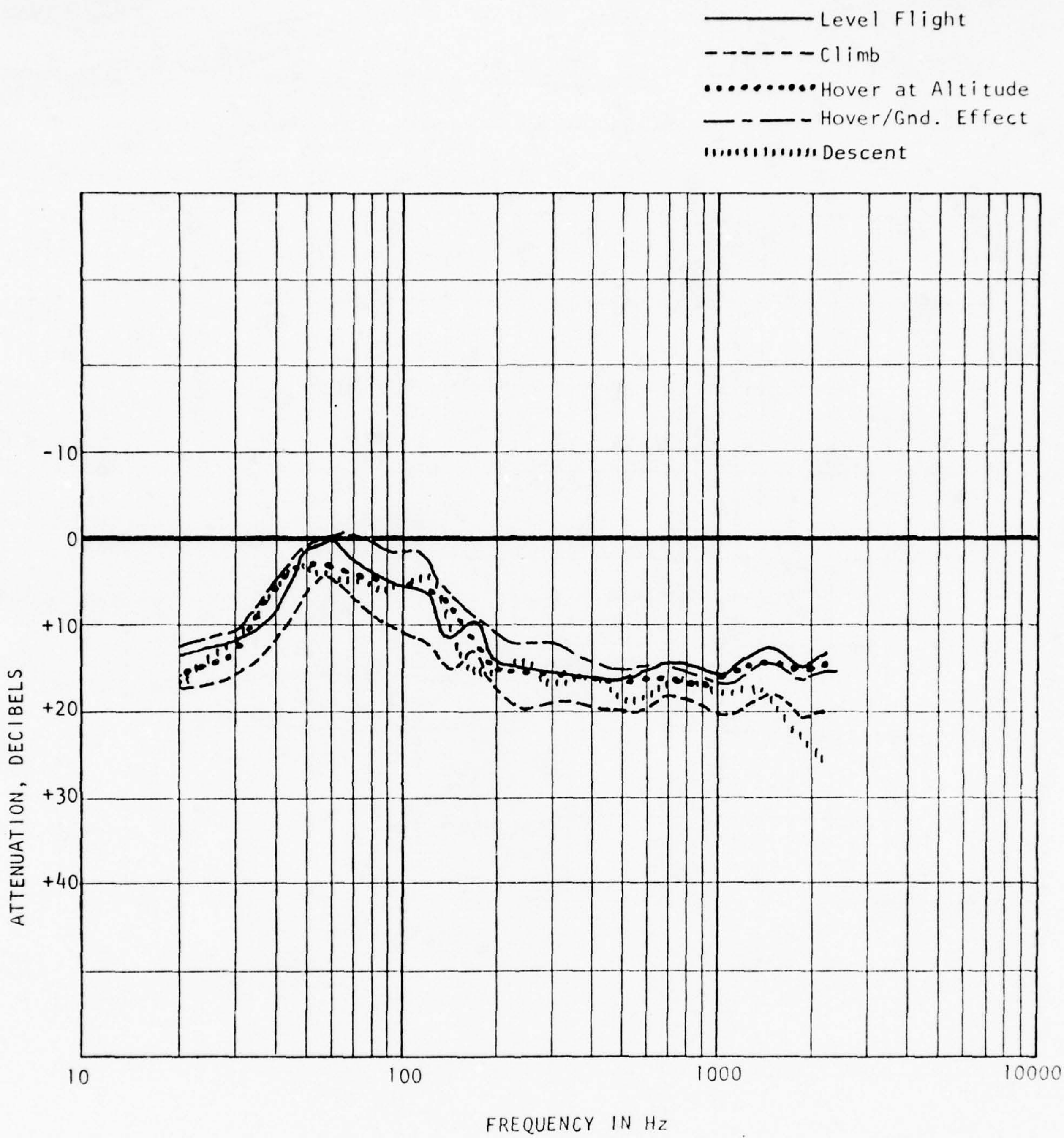


FIGURE 32 EARCUP ATTENUATION IN AN AH-1S HUEYCOBRA HELICOPTER, FOR 5 FLIGHT MODES: SAME DAY, SAME HUMAN SUBJECT

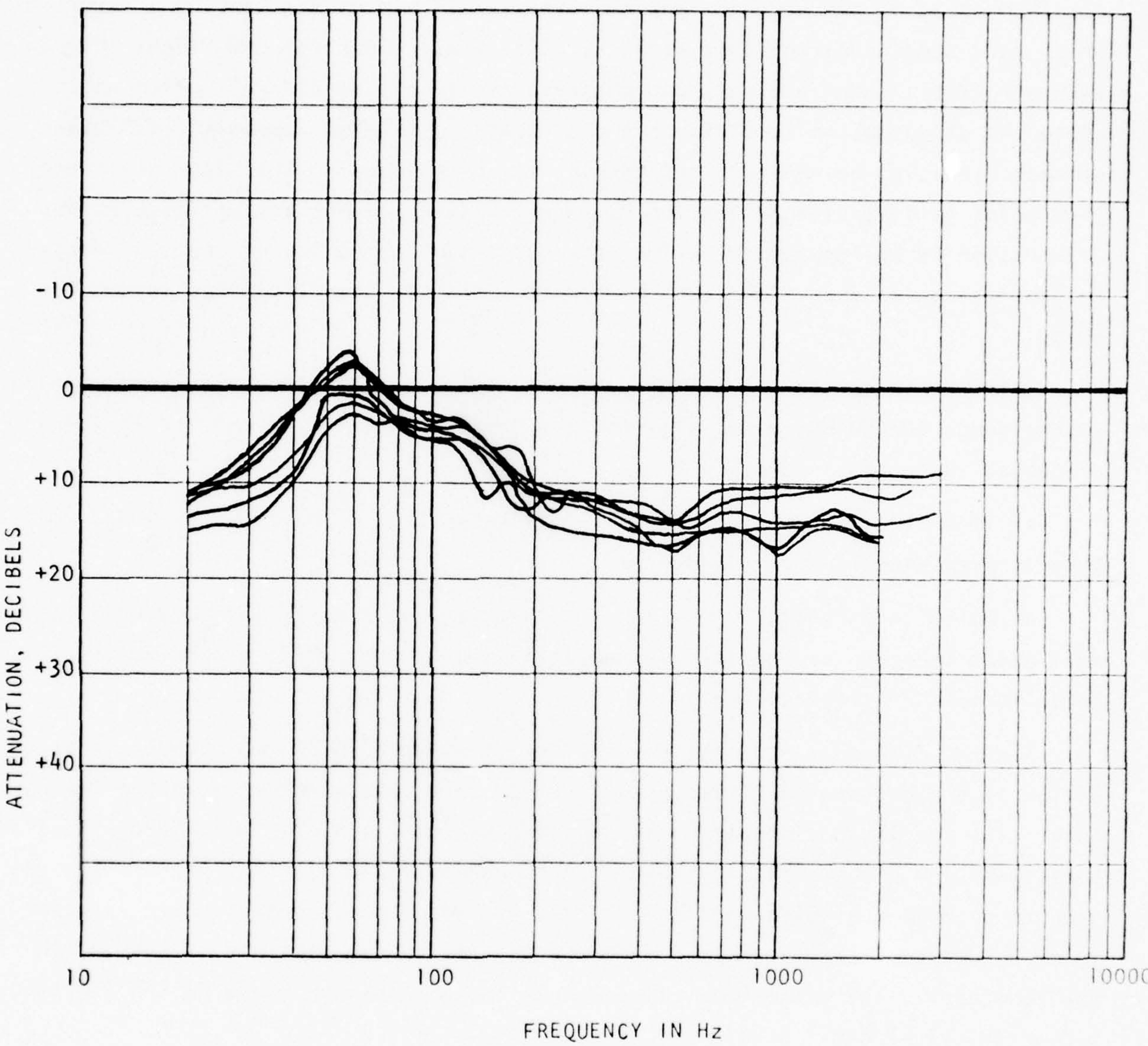


FIGURE 33 OVERLAY OF EARCUP ATTENUATIONS IN 3 AH-1S AND 3 AH-1Q HUEYCOBRA AIRCRAFT FOR LEVEL FLIGHT (EXCEPT ONE CURVE FOR ALTITUDE HOVER)

modes in one Hueycobra aircraft. The range of the curves shows the variability obtained on successive trails, even for the same human subject. Figure 33 is a simple overlay of the attenuations measured in all six of the Hueycobra aircraft which were studied during this project. Curves are shown for one flight mode in each aircraft. There are no known characteristics of the aircraft which would cause the attentuation to differ among aircraft. There is a possible influence of seat vibration being conducted through the body, causing the head to vibrate. This point is discussed in Section 7. A more likely reason for variable earcup attenuation is an improperly sealed ear cushion. The quality of the seal depends on such things as user technique, hair style, the wearing of glasses, and head shape.

There are numerous cases where the earcup attenuation was negative somewhere in the range 20-200 Hz, especially for the OH-58A. Likely reasons for this are discussed in detail in Section 7.

At 1000 Hz and above, the possibility of artifact noise must be considered. This is discussed in Appendix B.

As noted in Appendix B, the SPH-4 helmet was necessarily not located at the same point in space as the ambient-measuring microphone, which probably contributed to some of the variability.

Figures 30 and 31 show the possibility of about a 10 dB improvement in attenuation if the earcups performed as well in the aircraft as they do in the laboratory. The tabulations of earcup leakage and microphone pickup which are listed in Sections 4.1-4.6 show that the earcup performance is the limiting factor with regard to providing a noise environment free of damaging noise and speech interference. However, if the earcups performed as well in the aircraft as they do in the laboratory, the microphone noise-cancelling performance would be the limiting factor in all aircraft studied in this project.

4.8 STATISTICAL ANALYSIS

The ambient noise levels and spectra measured during this project are similar to those measured during other studies.[2-4,7]

There were large level differences (5-6 dB) among average sound levels for various flight conditions for some types of aircraft (UH-1H) but not for others (OV-1D, except during landing, and OH-58A). There were some extreme ambient level differences among individual aircraft of the same type. For example, the OV-1D with propellers not synchronized produces fully 10 dB more A-weighted noise than the typical aircraft.

Maximum performance maneuvers for the helicopters did not produce significantly more noise than standard maneuvers. Nor did the limited amount of relevant data show that open doors and windows cause more noise.

The measurements of overall sound levels within helicopters that are described in this report yielded as few as two values for a given flight condition for one type of aircraft (AH-1Q), and a maximum of 10 values for any particular aircraft (UH-1H). With such sparse data, there are questions about how accurately the variability of sound levels within Army helicopters has been defined. In other words, how much deviation from measured values can result from confluences of random factors such as meteorology, microphone position, pilots' control techniques, age of vehicles, structural variations, manufacturing tolerances, and measurement errors?

A first approximation of the variability of sound levels within helicopters can be obtained from the relatively few measured values by assuming that those sound levels are normally distributed (see any monograph on statistics). Other distributions may be more appropriate, but more data would be required even to determine the type of distribution.

When an average is calculated from a small number of values out of a large number of possible values, a "sample mean" is obtained. That sample mean is only an estimate of the average that would be calculated if all of the large number of possible values were available--the "universe mean". The smaller the number of available values, the cruder the sample estimate of the universe mean. Similarly, when a standard deviation (see any monograph on statistics) is calculated from a small number of values out of a large number of possible values, a "sample standard deviation" is obtained. That standard deviation is an estimate of the "universe standard deviation" that would be calculated if all of the large number of values were available, even when a routine calculation technique which is said to yield a standard deviation "unbiased by sample size" is used. The expected distribution of values for

sample standard deviations from a normally-distributed universe of values of a variable is described by a "student-t distribution" (see any monograph on statistics).

One can make use of the known properties of a normal distribution to define the degree of confidence in a sample estimate of a universe mean.[28] A sample mean and a sample standard deviation can be used to calculate an upper limit to a universe mean. The value of that limit will depend on the level of confidence that is required of that limit: in other words, the mathematical function of a sample mean and a sample standard deviation that is used to calculate the upper limit to a universe mean depends on how confident of the calculation one wishes to be.

Table 2 shows calculated values of sample means and sample standard deviations for the measurements of overall sound levels within helicopters that are described in this report. The sample average, $\overline{X}$, was calculated in the usual way:

$$\overline{X} = \frac{1}{N} \sum_{i=1}^{N} X_i \ ,$$

where N is the number of values, and X_i is the ith value. The "unbiased" sample standard deviation, σ, was calculated from:

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (X_i - \overline{X})^2} \ ,$$

where "unbiased" refers to division by (N-1) inside the radical. A "biased" standard deviation refers to division by N inside the radical. The level below which one is 95 percent confident that the universe mean falls was calculated from Duncan,[28]:

$$\overline{X}\big|_{95\%} = \overline{X} + \frac{1.645\ \sigma}{\sqrt{N}} \ ,$$

which assumes a Gaussian distribution. In addition, as a first approximation, the sample standard deviation was assumed to be equal to the universe standard deviation; as indicated on the table, more precise confidence intervals could be calculated from the "student-t" distribution of sample standard deviations

for a normally-distributed universe of values.[28] The 95 percent confidence level which includes 99.7 percent of all anticipated measured sound levels (the 95/99.7 level) was calculated by adding three standard deviations to the 95 confidence level for the universe mean.

A footnote in Table 2 compares the 95/99.7 level with maximum levels allowed by two military regulations (MIL-A-8806A[29]; TB Med 251[14] and one civilian regulation (OSHA[13]). Notice that we are 95 percent confident that noise levels in some of two models of helicopter will exceed MIL-A-8806 limits and OSHA limits, while some of four models of helicopter will exceed TB Med 251 limits (See Sections 3.3, 4.5 and 10.2). Additional measurements and further study will be required to construct more detailed and more precise conclusions concerning random variations of levels of measured noise within Army helicopters.

TABLE 2

STATISTICAL ANALYSIS OF HELICOPTER COCKPIT NOISE DATA

(assuming a Gaussian distribution of cabin noise levels)*

MEASURED SOUND LEVELS (dBA) FOR LEVEL FLIGHT

AIRCRAFT MODEL	MEASURED SOUND LEVELS WITHIN COCKPITS (dBA)	SAMPLE AVERAGE (dBA)	("UNBIASED") SAMPLE STANDARD DEVIATION (dB)	95% CONFIDENCE LEVEL OF UPPER LIMIT OF UNIVERSE MEAN** (dBA)	95% CONFIDENCE LEVEL WHICH INCLUDES 99.7% OF SOUND LEVELS (dBA)***
UH-1H	95 93 96 93 94 89 94 93 95 96	94	2	95	101
OH-58	92 89 87 93 92 99	92	4	95	107
OV-1D	98 100 102 104 100 100	101	2	102	108
AH-1S & AH-1Q	97 95 92 96 95 95	95	2	96	102
CH-47C	108 111 112	110	2	112	118
CH-54B	95 93 96 99 103 95	97	4	100	112
ALL AIRCRAFT		97	6	99	117

* See discussion in Section 4.6.

** assuming that the universe standard deviation = sample standard deviation; the "student-t" distribution for sample standard deviations could be used for more precise calculations of 95/99.7 percent sound levels.

*** MIL-A-8806 maximum = 111 dBA;
OSHA maximum = 109 dBA for 4 hours for typical SPH-4 attenuation;
TB Med 251 maximum = 104 dBA for 4 hours for typical SPH-4 helmet attenuation.
(See Sections 3.3, 4.7 and 10.2)

5.0 PSYCHOACOUSTIC PROFILES OF AIRCRAFT COMMUNICATIONS SYSTEMS

Methods for assessing risks of hearing loss are reported in Section 3.3. Glorig[16] pointed out a difficulty which was not discussed in Section 3.3 -- accounting for innumerable combinations of level and duration in real environments. Sound levels and accompanying durations within a given helicopter depend upon maneuvers, meteorological conditions, and electronic communication devices. The Tables in Appendix C show that sound levels within a given helicopter generally vary by around 5 decibels or less during maneuvers, with a few exceptions. By using the maximum sound levels which were measured during maneuvers of a given helicopter, slightly high numbers for predicted hearing loss will result. That conservatism is particularly justified since occasional sound levels much higher than time-averaged sound levels were observed, and since peak speech levels are 12 decibels higher than average speech levels.[19]

Peaks of speech sound pressure levels are so intermittent as to border on being transient or impulsive. Background speech levels, to which speech peaks add, border on being continuous. Very little is known about risks of hearing losses which are associated with combinations of impulsive sounds and continuous sound,[30,31] especially when peak sound levels begin to move towards the threshold of pain,[31] as they will if pilots turn up volume controls on communications equipment to maximum positions.

The fraction of flight time during which pilots and crews are exposed to electronic communication of speech is not known. The estimates of hearing loss which are presented below are based on the assumption that speech communications are conducted during one-half of one 4 hour flight each day. Since Camp et al[32] published curves which show that aircraft communications systems are used about 40 percent of flying time, that assumption may lead to slightly high estimates of noise induced hearing loss. However, since sound levels at a pilot's ears with and without speech generally do not differ greatly, the assumption introduces little error. An additional conservative factor is introduced by applying hearing loss curves for 40 years exposure to helicopter pilots and crew who serve less than 40 years. However, differences between hearing loss after 10 years exposure and after 40 years exposure are small.[11]

Table 3 summarizes the results of predictions of hearing loss. Those results are discussed below. All assessments of hearing loss which are discussed here apply only to personnel who wear helmets which provide at least as much protection as SPH-4 helmets.

Methods for computing articulation index are reported in Section 3.4. Methods for converting calculated values of articulation index to estimates of the intelligibility of sentences were reported in Section 3.5. The factors which limit the accuracy of estimates of intelligibility also were reported in that section.

5.1 UH-1H

The intelligibility of electronically communicated speech within these aircraft was calculated to be 97 to 99 percent. Intelligibility was as low as 56 percent during one maneuver of an aircraft (68-16612) from which sound absorptive material had been removed. Estimates of hearing loss by protected occupants of these aircraft range from no risk of measurable hearing loss at "speech frequencies," to a 5 to 10 dB NIPTS at speech frequencies among 35 percent of frequent occupants, coupled with an NIPTS of more than 10 dB at "speech frequencies" for 1.5 percent of frequent occupants.

5.2 OV-1D

The intelligibility of electronically communicated speech within these aircraft was calculated to be 93 to 99 percent. Intelligibility was as low as 72 percent during one maneuver of one aircraft (68-16996). Predictions of hearing loss by protected occupants of these aircraft range from no measurable loss at "speech frequencies" to a 5 to 10 dB NIPTS at "speech frequencies" among 90 percent of frequent occupants, combined with an NIPTS of more than 10 dB at "speech frequencies" among 25 percent of frequent occupants.

5.3 OH-58

The intelligibility of electronically communicated speech within these aircraft was calculated to be 97 to 99 percent. Predictions of hearing loss by protected occupants of these aircraft range from no measurable loss at "speech frequencies" to a 5 to 10 dB NIPTS at "speech frequencies" among 26 percent of frequent occupants, and an NIPTS greater than 10 dB for one percent of those occupants.

TABLE 3

PREDICTED HEARING LOSS AMONG HELICOPTER PILOTS AND CREWS
(BASED ON MEASURED SOUND LEVELS AT PILOTS' EARS)

AIRCRAFT	MAXIMUM SOUND LEVEL DURING SPEECH (dBA)	MAXIMUM SOUND LEVEL, NO KEY, NO SPEECH (dBA)	MAXIMUM EQUIVALENT 4 HOUR LEVEL (dBA)	CALCULATED INTELLIGIBILITY (%)	MAXIMUM PREDICTED HEARING DAMAGE** (applies to frequent occupants who wear SPH-4 helmets; applies to "speech frequencies")
UH-1H 66-16054	-	-	-	-	------
66-16566	91	86	89	99	1%, 5 to 10 dB NIPTS
68-16612	86	85	85	61-97	immeasurably small
68-16622	90	86	88	99	Immeasurably small
68-16628	97	87	94*	-	17%, 5 to 10 dB NIPTS
69-15008	98	92	96*	99	35%, 5 to 10 dB NIPTS; 1.5% > 10 dB NIPTS
71-20223	93	91	92*	-	7%, 5 to 10 dB NIPTS
71-20228	89	90	89	98	1%, 5 to 10 dB NIPTS
71-20254	86	81	84	99	immeasurably small
73-21693	90	86	88	93	immeasurably small
OV-1D 68-15933	91	90	90	98	2%, 5 to 10 dB NIPTS
68-15950	95	94	94*	-	17%, 5 to 10 dB NIPTS
68-15959	95	96	95*	93	26%, 5 to 10 dB NIPTS; 1% > 10 dB NIPTS
68-16996	102	97	100*	72-88	90%, 5 to 10 dB NIPTS; 25% > 10 dB NIPTS
68-16997	94	92	93*	97-99	10%, 5 to 10 dB NIPTS
69-17005	89	86	88	-	immeasurably small
OH-58 71-20475	86	84	85	-	immeasurably small
71-20558	88	90	89	98-99	1%, 5 to 10 dB NIPTS
71-20561	-	-	-	-	-----
71-20563	97	92	95*	97-99	26%, 5 to 10dB NIPTS; 1% > 10 dB NIPTS
71-20564	85	83	84	98	immeasurably small
71-20549	90	88	89	-	1%, 5 to 10 dB NIPTS

* Above maximum allowed (90 dBA) by TB MED 251 for daily 4 hour exposures.

(Continued on next page)

** For daily 4 hour exposures, for 40 years; however most of the hearing damage occurs during the first 10 years.

TABLE 3 (CONTINUED)

PREDICTED HEARING LOSS AMONG HELICOPTER PILOTS AND CREWS
(BASED ON MEASURED SOUND LEVELS AT PILOTS' EARS)

AIRCRAFT	MAXIMUM SOUND LEVEL DURING SPEECH (dBA)	MAXIMUM SOUND LEVEL, NO KEY, NO SPEECH (dBA)	MAXIMUM EQUIVALENT 4 HOUR LEVEL (dBA)	CALCULATED INTELLIGIBILITY (%)	MAXIMUM PREDICTED HEARING DAMAGE** (applies to frequent occupants who wear SPH-4 helmets; applies to "speech frequencies")
AH-1S 68-15177	86	84	85	96-97	immeasurably small
70-16010	89	88	90	99	2%, 5 to 10 dB NIPTS
70-16038	90	91	91*	98-99	4%, 5 to 10 dB NIPTS
71-20988	90	89	89	98-99	1%, 5 to 10 dB NIPTS
AH-1Q 68-15209	87	87	87	98-99	immeasurably small
70-15945	90	87	88	99	immeasurably small
CH-47C 70-15003	91	93	92*	49-83	7%, 5 to 10 dB NIPTS
70-15020	93	93	93*	-	10%, 5 to 10 dB NIPTS
70-15026	93	94	94*	-	17%, 5 to 10 dB NIPTS
CH-54B 69-18465	88	84	86	97-98	immeasurably small
69-18468	87	84	85	97-98	immeasurably small
69-18470	94	93	94*	88-94	17%, 5 to 10 dB NIPTS
69-18473	91	89	90	90-96	2%, 5 to 10 dB NIPTS
69-18476	97	93	98*	91-98	60%, 5 to 10 dB NIPTS; 8%, > 10dB NIPTS
69-18490	91	86	89	95-96	1%, 5 to 10 dB NIPTS

* Above maximum allowed (90 dBA) by TB MED 251 for daily 4 hour exposures.

** For daily 4 hour exposures, for 40 years; however most of the hearing damage occurs during the first 10 years.

5.4 AH-1S AND AH-1Q

The intelligibility of electronically communicated speech within these aircraft was calculated to be 96 to 99 percent. Predictions of hearing loss by protected occupants of these aircraft range from no measurable loss at "speech frequencies" to a 5 to 10 dB NIPTS at "speech frequencies" among 4 percent of frequent occupants.

5.5 CH-47C

The intelligibility of electronically communicated speech within these aircraft was calculated to be 49 to 83 percent. Predictions of hearing loss by protected occupants of these aircraft range from a 5 to 10 dB NIPTS at "speech frequencies" among 7 percent of frequent occupants to an identical loss among 17 percent of frequent occupants.

5.6 CH-54B

The intelligibility of electronically communicated speech within these aircraft was calculated to be 88 to 98 percent. Predictions of hearing loss by protected occupants of these aircraft range from no measurable loss at "speech frequencies" to a 5 to 10 dB NIPTS at "speech frequencies" among 60 percent of frequent occupants, combined with an NIPTS of more than 10 dB at "speech frequencies" among 8 percent of frequent occupants.

5.7 SENSITIVITY OF HEARING LOSS ESTIMATES TO SOUND LEVEL

The estimates of hearing loss which are presented in Section 5.1 through 5.6 were based on the highest sound levels that were measured during many maneuvers. Some justifications for that procedure were previously presented in Section 5.0. The degree of conservatism introduced by that procedure is illustrated by re-estimating hearing damage risks for a couple of other choices at sound levels for the aircraft which generated the widest range (7 dB) of measured sound levels--the OV-1D number 68-16996.

Using the highest measured sound level measured for the number 68-16996 OV-1D results in an estimate of a 5 to 10 dB NIPTS for 90 percent of frequent occupants, coupled with an NIPTS of more than 10 dB for 25 percent of those occupants. If the mid-range value of measured sound levels is used, the resulting estimate is a 5 to 10 dB NIPTS for 48 percent, combined with an NIPTS of

more than 10 dB for 4 percent. Using the lowest values results in an estimate of a 5 to 10 dB NIPTS for 19 percent of frequent occupants. This sensitivity to choice of values among measured sound levels is the greatest one for the list of damage risks shown in Table 3. since the range of measured sound level is the greatest for this case.

5.8 COMPARISON OF RESULTS WITH THOSE OF PREVIOUS STUDIES

The levels of intrusive noise which are tabulated in Table 3 are close to levels defined by Gasaway[22] as threshold levels for which the intrusion of ambient noise begins to create noticable interference with aural communications. The intelligibility levels which are tabulated in Table 3 agree with Gasaway's conclusion that the background noise levels are marginally adequate, since the tabulated values for intelligibility vary with the levels of background noise. If there were any leeway in noise levels, then intelligibility scores would remain high for varying levels of background noise.

An extensive literature search revealed no publications which relate specific amounts of hearing loss to exposure to helicopter noise, nor have there been published attempts to predict how many people will suffer given levels of hearing loss as a result of exposure to helicopter noise. There is a pronounced need to study hearing losses among helicopter pilots and crew members whose exposures to noise both on and off duty are well defined and documented. It is difficult to keep track of their exposure to noise while they are not on duty within a helicopter. That exposure could be defined for a study group of typical helicopter occupants by performing audiometric tests of their hearing on frequent, randomly-selected occasions at the beginning of their daily duty.

5.9 HEARING LOSSES AMONG ARMY PERSONNEL BEFORE THEY BECOME HELICOPTER PILOTS

Walden, et al[33] published measurements which show that, while the vast majority of individuals entering the Army have hearing within normal limits, in the first four to six months that an individual is on active duty, his chances of sustaining a hearing impairment increase substantially as his time on active duty continues. For example, they reported that 5 percent of individuals who complete basic and advanced training suffer hearing losses at the end of that training of sufficient magnitude that they should be removed from the job for which they have just been trained.

Many helicopter pilots are drawn from experienced infantry, artillery, and armor personnel. Table 4 shows that over half of those personnel have suffered significant hearing losses at the time that they enter helicopter service, and one-quarter to one-half of them have suffered severe hearing losses which make them unsuitable for duty in high-noise environments at the time that they enter helicopter service.

5.10 CONCLUSIONS

The noise levels that are listed in this report are in agreement with levels which were measured and published by other investigators. Currently accepted criteria for predicting hearing losses which result from noise exposure lead one to conclude that those noise levels will cause what is currently accepted to be a hearing handicap (see Section 3.3) in only a small fraction of one percent of all exposed personnel who wear helmets at least as good as SPH-4 helmets. However, the measurements which are described in this report were performed with volume controls set at mid-range. If pilots routinely turn up volume controls on their communication aids because of real or imagined problems with intelligibility, then large percentages of them will suffer handicapping losses of hearing.

Tables 5 and 6 show the calculated effects of turning up electronically-generated signals and noise by 10 decibels. When that is done, low frequency noise which is transmitted mechanically through earcups is not changed. The result is that a pilot does achieve a considerable improvement in intelligibility by turning up volume controls. Those Tables also show that pilots increase overall A-weighted speech and noise levels by almost 10 dB when they turn up the gain by 10 dB; such changes in overall sound level correspond to a significant increase in risks of loss of hearing.

It is likely that pilots turn up volume controls on communications aids in attempts to raise speech levels above the level of intruding low frequency noise that is transmitted through helmets and earcups (see Sections 4.7 and 8.2). If that low frequency noise could be eliminated, then pilots would be more inclined to set speech levels at less than harmful levels, and they would feel more comfortable and be less subject to fatigue and error and risks of hearing loss would be even less than those small risks which are described in this section.

TABLE 4

PERCENTAGES OF MILITARY PERSONNEL WHO HAVE SUFFERED THE INDICATED LEVELS OF HEARING LOSS AFTER MORE THAN 10 YEARS ACTIVE DUTY (WALDEN, et al[33])

DEGREE OF HEARING LOSS	INFANTRY	ARTILLERY	ARMOR
(H1) NO SIGNIFICANT LOSS	47.2	47.9	36.7
(H2) SUBSTANTIAL LOSS	25.8	19.1	20.0
(H3) SHOULD REQUIRE MANDATORY DUTY LIMITATIONS	23.0	29.8	40.9
(H4) SHOULD BE DISCHARGED	4.0	3.2	2.3

TABLE 5. EFFECTS OF INCREASED VOLUME CONTROL SETTINGS (UH-1H)

UH-1H 68-16612, LEVEL FLIGHT
GAIN STUDY. ORIGINAL LEVELS.

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	47.4	61.2
380.0	45.9	53.4
490.0	53.9	47.1
630.0	51.5	44.4
770.0	42.3	39.9
920.0	39.2	34.2
1070.0	37.8	33.9
1230.0	39.3	37.3
1400.0	42.0	36.5
1570.0	42.9	36.2
1740.0	40.2	36.1
1920.0	37.2	37.6
2130.0	36.4	38.7
2370.0	34.8	36.8
2660.0	33.1	45.3
3000.0	42.3	50.9
3400.0	29.6	45.0
3950.0	33.6	36.4
4560.0	24.0	34.3
5600.0	18.0	30.6
OASL(DBA) =	77.8	81.9

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 83.3 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	61.2	26.7	61.2
380.0	53.4	21.8	53.4
490.0	47.1	18.1	47.1
630.0	44.4	14.5	44.4
770.0	39.9	11.6	39.9
920.0	34.2	9.1	34.2
1070.0	33.9	6.9	33.9
1230.0	37.3	4.9	37.3
1400.0	36.5	3.0	36.5
1570.0	36.2	1.3	36.2
1740.0	36.1	0.6	36.1
1920.0	37.6	0.0	37.6
2130.0	38.7	0.0	38.7
2370.0	36.8	0.0	36.8
2660.0	45.3	0.0	45.3
3000.0	51.1	0.0	51.1
3400.0	45.0	0.0	45.0
3950.0	36.4	0.0	36.4
4560.0	34.3	34.3	34.3
5600.0	30.6	0.0	30.6

ARTICULATION INDEX = .34

TABLE 5. EFFECTS OF INCREASED VOLUME CONTROL SETTINGS (UH-1H) (Continued)

UH-1H 68-16612, LEVEL FLIGHT
GAIN STUDY. RAISE NOISE SPL AVOVF 1000 HZ AND ALL SPEECH SPL BY 10 DB.

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	57.4	61.2
360.0	55.9	53.4
490.0	63.9	47.1
630.0	61.5	44.4
770.0	52.3	39.9
920.0	49.2	34.2
1070.0	47.8	43.9
1230.0	49.3	47.3
1400.0	52.0	46.5
1570.0	52.9	46.2
1740.0	50.2	46.1
1920.0	47.2	47.6
2130.0	46.4	48.7
2370.0	44.8	46.8
2660.0	43.1	55.3
3000.0	52.3	60.9
3400.0	39.6	55.0
3950.0	43.6	46.4
4560.0	34.0	44.3
5600.0	28.0	40.6

OASL(DBA) = 87.8 90.6

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 92.4 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	61.2	38.6	61.2
360.0	53.4	33.7	53.4
490.0	47.1	30.0	47.1
630.0	44.4	26.4	44.4
770.0	39.9	23.5	39.9
920.0	34.2	20.9	34.2
1070.0	43.9	18.7	43.9
1230.0	47.3	16.7	47.3
1400.0	46.5	14.9	46.5
1570.0	46.2	13.2	46.2
1740.0	46.1	11.7	46.1
1920.0	47.6	10.3	47.6
2130.0	48.7	8.8	48.7
2370.0	46.8	7.3	46.8
2660.0	56.2	5.6	56.2
3000.0	63.1	3.9	63.1
3400.0	56.0	57.3	57.3
3950.0	46.4	0.0	46.4
4560.0	44.3	44.3	44.3
5600.0	40.6	0.0	40.6

ARTICULATION INDEX = .43

TABLE 6. EFFECTS OF INCREASED VOLUME CONTROL SETTINGS (OV-1D)

OV-1D =68-16997, LEVEL FLIGHT
GAIN STUDY. ORIGINAL LEVELS.

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	72.6	70.3
380.0	54.3	56.7
490.0	52.6	49.[illegible]
630.0	51.4	47.5
770.0	48.5	41.3
920.0	45.0	38.2
1070.0	45.3	37.6
1230.0	46.4	38.2
1400.0	47.2	39.2
1570.0	47.5	38.[illegible]
1740.0	46.2	36.5
1920.0	44.0	34.6
2130.0	44.2	36.0
2370.0	46.5	37.0
2660.0	55.8	49.5
3000.0	54.9	55.5
3400.0	51.0	52.5
3950.0	21.3	44.4
4560.0	-19.0	43.1
5600.0	-20.2	38.5

OASL(DBA) = 89.6 83.1

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 91.9 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	70.3	32.9	70.3
380.0	56.7	27.9	56.7
490.0	49.8	24.3	49.8
630.0	47.5	20.6	47.5
770.0	41.3	17.7	41.3
920.0	38.2	15.2	38.2
1070.0	37.6	13.0	37.6
1230.0	38.2	11.0	38.2
1400.0	39.2	9.1	39.2
1570.0	38.7	7.5	38.7
1740.0	36.5	6.0	36.5
1920.0	34.6	4.6	34.6
2130.0	36.0	3.1	36.0
2370.0	37.0	1.5	37.0
2660.0	49.5	0.0	49.5
3000.0	56.6	0.0	56.6
3400.0	53.0	51.4	53.0
3950.0	44.4	0.0	44.4
4560.0	43.1	0.0	43.1
5600.0	38.5	0.0	38.5

ARTICULATION INDEX = .49

TABLE 6. EFFECTS OF INCREASED VOLUME CONTROL SETTINGS (OV-1D) (Continued)

OV-1D 68-16997, LEVEL FLIGHT

GAIN STUDY. RAISE NOISE SPL ABOVE 1800 HZ AND ALL SPEECH SPL BY 10 DB.

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	82.6	70.3
380.0	64.3	56.7
490.0	62.6	49.8
630.0	61.4	47.5
770.0	58.5	41.3
920.0	55.0	38.2
1070.0	55.3	37.6
1230.0	56.4	38.2
1400.0	57.2	39.2
1570.0	57.5	38.7
1740.0	56.2	36.5
1920.0	54.0	44.6
2130.0	54.2	46.0
2370.0	56.5	47.0
2660.0	65.8	59.5
3000.0	64.9	65.5
3400.0	61.0	62.5
3950.0	31.3	54.4
4560.0	-19.0	53.1
5600.0	-20.2	48.5

OASL(DBA) = 99.6 96.0

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 101.2 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	70.3	44.9	70.3
380.0	56.7	39.9	56.7
490.0	49.8	36.3	49.8
630.0	47.5	32.6	47.5
770.0	41.3	29.7	41.3
920.0	38.2	27.2	38.2
1070.0	37.6	25.0	37.6
1230.0	38.2	23.0	38.2
1400.0	39.2	21.1	39.2
1570.0	38.7	19.5	38.7
1740.0	36.5	18.0	36.5
1920.0	44.6	16.6	44.6
2130.0	46.0	15.1	46.0
2370.0	47.0	13.5	47.0
2660.0	61.2	11.9	61.2
3000.0	68.6	10.1	68.6
3400.0	65.0	62.4	65.0
3950.0	55.1	63.4	63.4
4560.0	53.1	64.5	64.5
5600.0	48.5	36.2	48.5

ARTICULATION INDEX = .66

There is little chance of modifying existing helicopters to reduce the levels of low frequency sound to non-intrusive levels (See Section 8.1). Modifications of helmets and earcups or more effective use of earcups by personnel are the most likely means for reducing the noise significantly (See Section 8.2). Earplugs provide a less appealing, but effective, means for controlling the intrusion of low frequency noise. Some people have expressed concern that earplugs might prevent equalization of pressure within ears during rapid altitude changes. However, Stork and Gasaway[34] conducted studies which provided evidence that most people can wear earplugs in flight without discomfort and without difficulty in ventilating their middle ears.

Whatever the methods for controlling the levels of noise at people's ears, routine periodic audiometric tests should be performed on people who are exposed to high intensity sound. There is enough doubt about the accuracy of hearing loss data,[15] and enough individual variation from trends for large populations, that limits on noise exposure do not insure that given individuals will not suffer significant hearing losses when they are exposed to noise which is controlled to meet popular damage risk criteria.

The need for frequent audiometric testing of people who are exposed to high intensity sound has been recognized by the military services since 1949.[35] Since 1956, the Air Force has performed an annual audiometric test of each noise-exposed person within the Air Force. Early indications of a growing loss of hearing is cause for removing a person from noisy work conditions, well before a significant hearing handicap is established. The result is that noise-exposed military and civilian personnel employed by the Air Force hear better than the general population of the U.S.; that difference cannot be attributed entirely to entry standards. The U. S. Army has adopted a similar program. A description of military programs is found in Section 9.2.

6.0 ANALYSIS OF AVIONICS EQUIPMENT

Part of the data supplied by AEL is in the form of electrical measurements made on radios and aircraft intercommunication (AIC) sets. The performance of AIC's will be discussed in this section.

Data were provided on the gain and harmonic distortion of the microphone and headset amplifiers. These are summarized in Table 7. The microphone tests at small and large input voltages show that the AGC circuits are operating satisfactorily and that the distortion is low. After allowance for an attenuation of 66 dB in the input test circuit, and allowance for the sensitivity of a typical M-87 microphone (-111 dBV/μbar),[6] the test voltage of 0.6 Volts simulates a sound pressure of about 115 dB SPL; 4.0 Volts simulates a sound pressure of about 131 dB SPL.

The headset amplifier output of 1.25 Volts produces approximately 100 dB SPL in the earcup. For both AIC's, the distortion exceeds 5% at some frequencies. This distortion, although exceeding specifications, probably has no adverse effect on intelligibility.

When the signal to the earphone is raised from 1.25 Volts to 1.5 Volts, the C-1611D distorts severely, whereas the distortion of the C-6533 does not increase.

AEL personnel performed a few distortion tests on an AN/ARC-115 VHF-AM radio, serial no. 25959, which permit assessing the relative distortion in the C-6533 and the receiver. The following result is typical. A standard 80% modulated RF signal was applied at 131.150 MHz.

AIC OUTPUT (mW)	RECEIVER VOLUME	DISTORTION (%)
200	Maximum	24.5
253 (Max)	Mid-range	19
200	Mid-range	4.8

This result indicates that at maximum volume settings at this input signal level, the AIC and receiver audio circuit contribute about equally to distortion.

Another set of electrical measurements was available in the form of tape recordings of the electrical noise at the output of the headset amplifier. The headset was simulated by an 8 ohm resistor. Measurements were made with the

TABLE 7 AIC AVERAGE PERFORMANCE

AIC TYPE	C-1611D	C-6533	C-1611D	C-6533
COMPONENT	Microphone Amplifier	Microphone Amplifier	Headset Amplifier	Headset Amplifier
NUMBER TESTED	12	11	13	11
TEST INPUT (VOLTS)	0.6	0.6	2.75	2.75
FREQ. RESPONSE (Hz) (3db POINTS)	130-7000	250-4600	145-7000	125-9000
OUTPUT (VOLTS)	2.6	2.9	1.25 (Volume adjustment)	1.25 (Volume adjustment)
HARMONIC DISTORTION (%) 1000 Hz	2.2	1.3	4.5	3.7
DISTORTION RANGE (%) 1000 Hz	1.6-4.0	0.6-2.6	2.9-8.0	3.4-4.3
HARMONIC DISTORTION (%) 300 Hz/6000 Hz	Same as 1000 Hz	Same as 1000 Hz	7.0/5.4 (2 units)	3.8/5.2 (3 units)
LARGE SIGNAL TEST INPUT (VOLTS)	4.0	4.0	2.75 (Volume max.)	2.75 (Volume max.)
LARGE SIGNAL OUTPUT (VOLTS)	3.9 (4 units)	3.1 (2 units)	1.55	1.51
LARGE SIGNAL DISTORTION (%) 1000 Hz	2.6 (4 units)	1.3 (2 units)	24.5	3.6

AIC both keyed and not keyed, and with both a real and simulated M-87 microphone. The contribution to acoustic noise at the ear due to electrical self-noise in the amplifiers was found to be negligible. The values of the sound pressure which would be produced at the ear by these electrical sources could not be precisely calculated because of uncertainty about the exact calibration of the earphone in situ and because of the problem of tape recorder noise at the low levels encountered. The following values represent a worst case estimate and a most probable estimate of the sound at the ear due to amplifier noise, compared to the noise due to all acoustic sources.

- o Worst case estimate: Noise (in dBA) due to electrical sources is 30 dB below noise (in dBA) due to acoustical sources.
- o Most probable estimate: Noise (in dBA) due to electrical sources is 50 dB below noise (in dBA) due to acoustical sources.

A few measurements were made to test the action of AGC in the microphone amplifier upon the initiation of the speech test-phrase. The method is described in Appendix B. Due to various problems in inserting the test signal and interpreting the results, the confidence level of the accuracy of the values is only moderate.

AIRCRAFT TYPE	AMPLIFIER GAIN CHANGE (dB)
UH-1H	-3.1 (one sample)
OV-1D	-3.6 (one sample)
AH-1S	-5.1 (three samples)

These values were not used to adjust the KEY NO TALK noise (above the crossover frequency) downward before calculation of the articulation indices which are listed in this report. Had they been used, the listed indices would have been slightly better. For example, in the case of the OV-1D #69-17005, the index increases from .40 to .44 when AGC action is taken into account.

7.0 EXPERIMENTAL STUDIES OF EARCUPS

In Section 4, it is shown that earcups are the weak link in the aircraft communication system with regard to reducing noise at the ear. A series of experiments were made to determine why the SPH-4 has deficient performance in the aircraft. Before beginning the experiments, the literature was reviewed. The theory of circumaural earcups has been described by Zwislocki,[36,37] Shaw and Thiessen[38,39] and others. Following are mechanisms cited for sound transmission through or around earcups.

- o Sound leakage through spaces between the earcup cushion and the head.
- o Vibration of the earcup as a unit relative to the head. Caused by external sound pressure, the vibration modulates the internal earcup pressure, thus producing sound at the ear. This phenomenon has been referred to as "earcup pumping" or the "pumping mode."
- o Local flexure of the earcup wall or earcup cushion.
- o Sound transmission into the earcup volume through the flesh immediately under the earcup cushion.
- o Sound transmission through the chest and head (bone conduction) to the middle ear. This is known to limit the attenuation of all types of ear defenders to about 45 dB throughout the spectrum.[40]

7.1 EXPERIMENTS WITH THE SPH-4 ON A FLAT PLATE COUPLER

Figures 34 through 37 show the results of an investigation of various factors which contribute to reduced attenuation in the SPH-4. The tests were made at ATC on the same helmet which was used by USAECOM for the in-flight measurements. A few tests were made on a different but similar set of SPH-4 earcups. The earcups and cushions were in good condition. A test sound pressure of 94 dB SPL was applied. The helmet straps were used to apply approximately one kilogram-force to the earcup. The tests were made by pressing the SPH-4 earcup against a flat plate which was built up slightly with clay to provide a contoured surface. The contoured surface facilitates making a good seal. The reference pressure was measured just outside the earcup; thus diffraction effects do not appear in the results. A single loudspeaker in an anechoic chamber was used as a sound source.

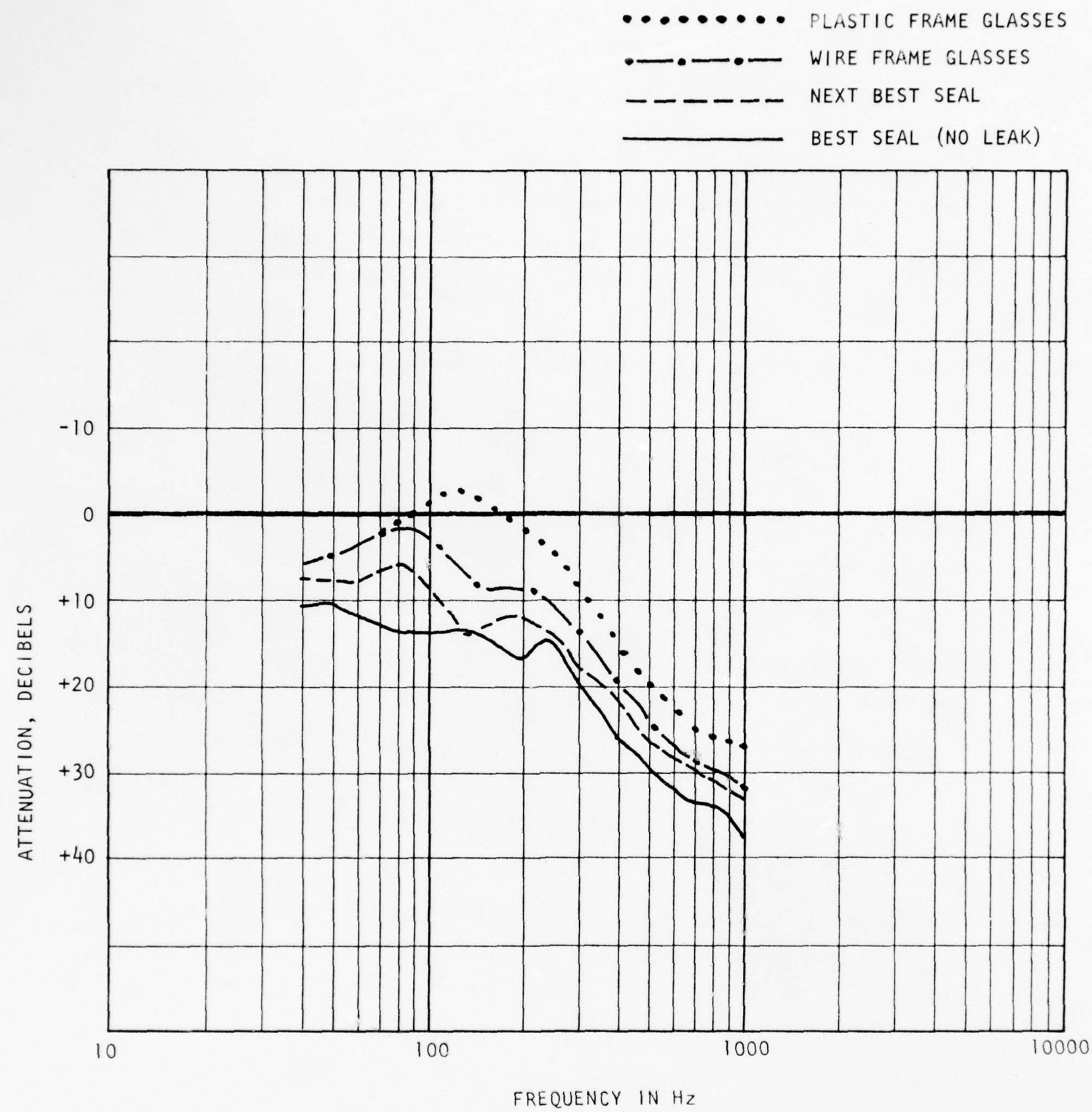


FIGURE 34. ATTENUATION DEPENDENCE ON LEAKS UNDER EAR CUSHION - SPH-4 MOUNTED ON FLAT PLATE (MODIFIED WITH CLAY)

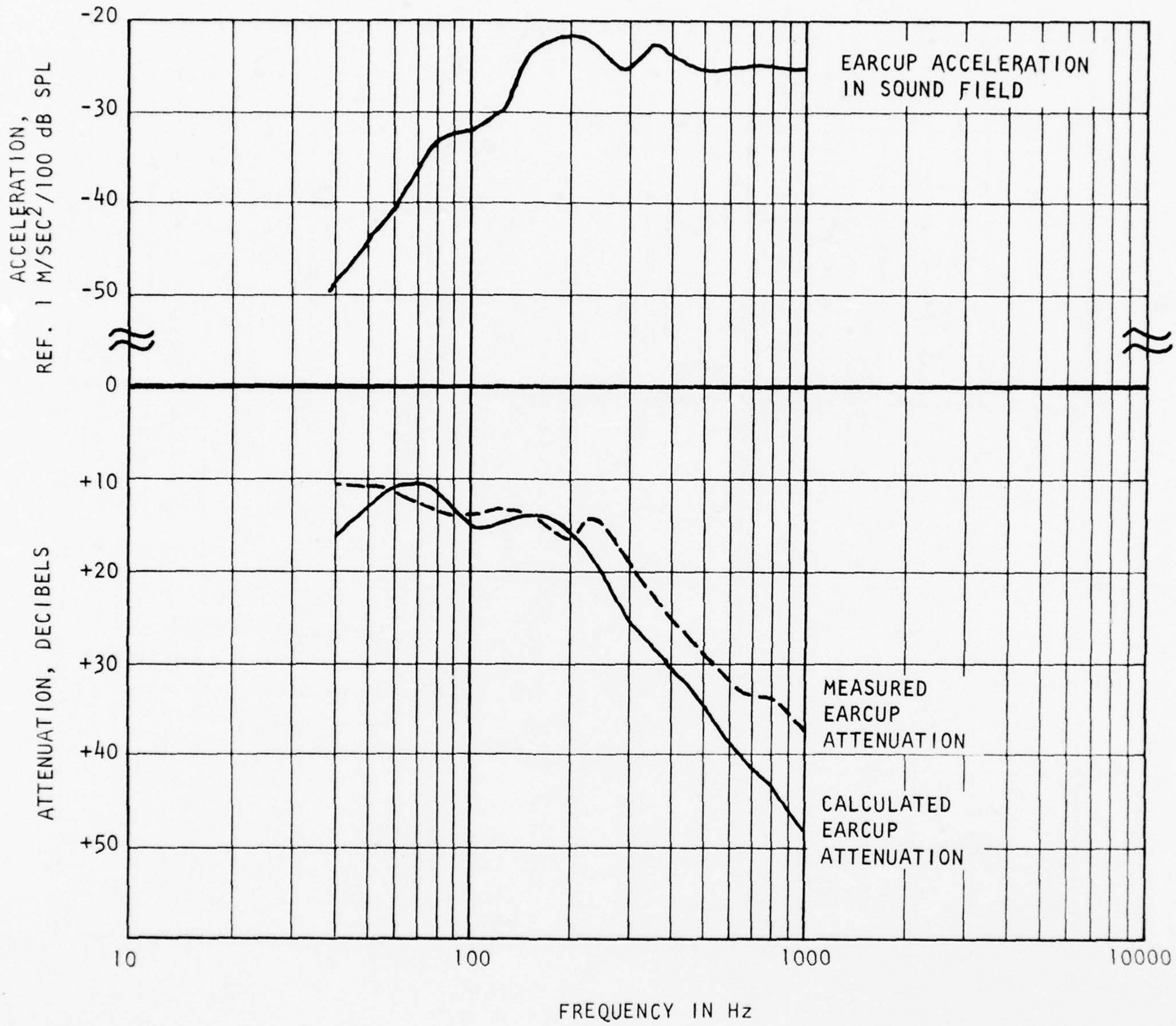


FIGURE 35. CALCULATED EARCUP ATTENUATION DERIVED FROM VIBRATION MEASUREMENTS, COMPARED TO MEASURED ATTENUATION -- SPH-4 MOUNTED ON FLAT PLATE MODIFIED WITH CLAY

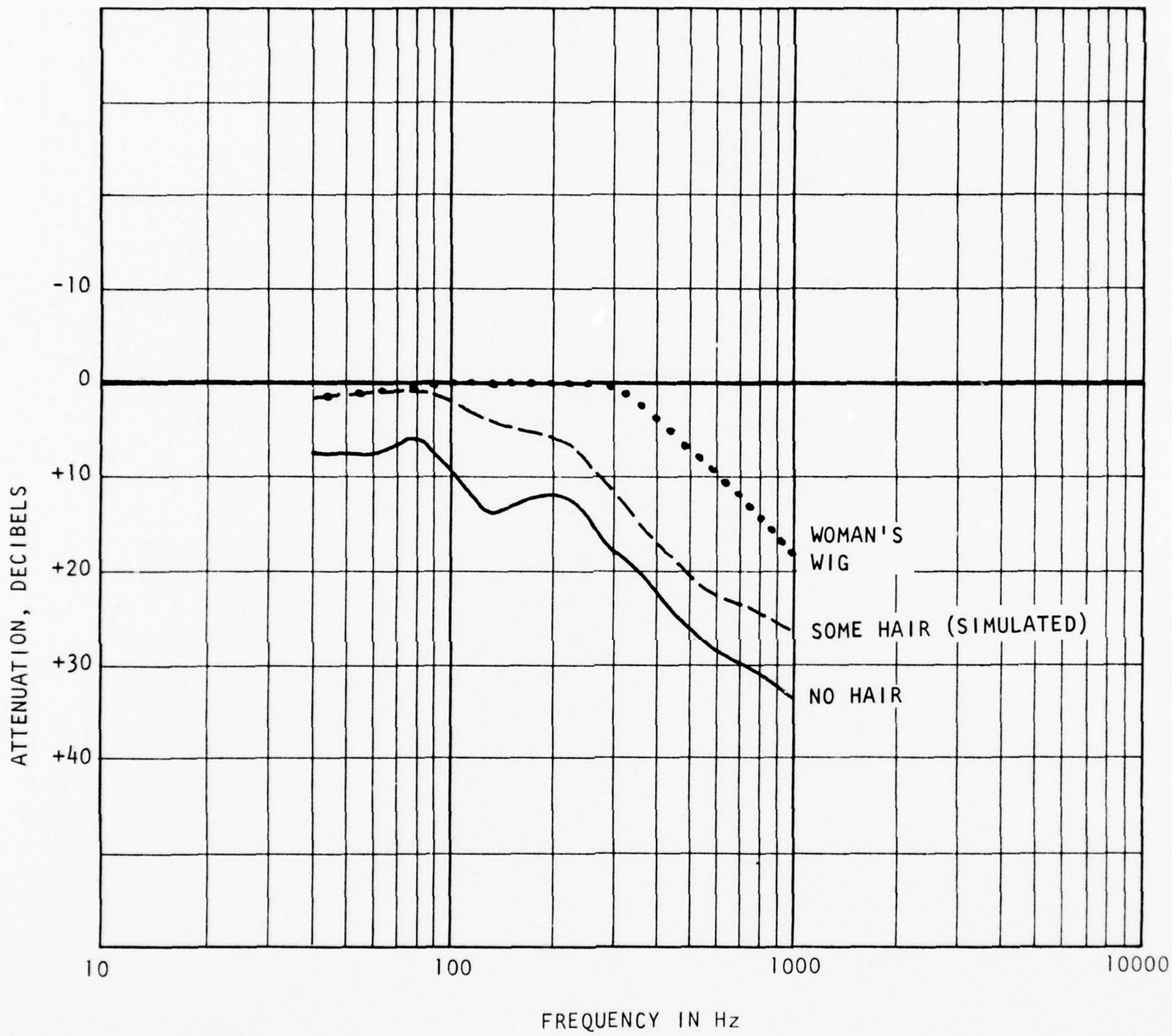


FIGURE 36. EFFECT OF HAIR STYLE ON ATTENUATION -- SIMULATED ON FLAT PLATE (MODIFIED WITH CLAY)

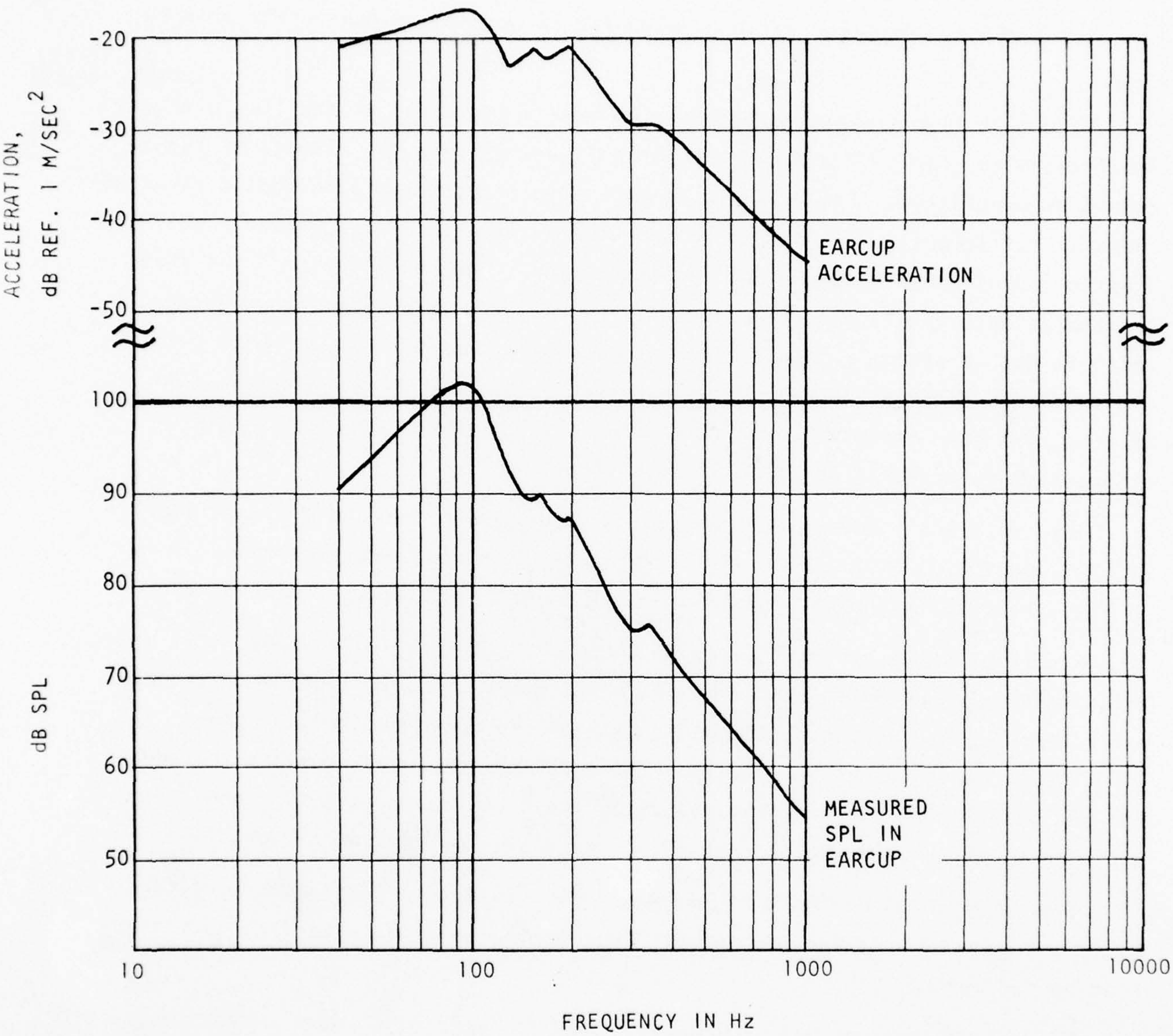


FIGURE 37. SOUND PRESSURE PRODUCED IN SPH-4 EARCUP DUE TO FLAT PLATE (SIMULATED HEAD) VIBRATION OF 0.1 M/SEC^2 (APPROXIMATELY 0.01 g)

A number of the individual earcup attenuation measurements which went into the averages plotted in Figures 30 and 31 showed a negative attenuation somewhere in the region 20-200 Hz. This is evidence of a resonance condition, due either to sound leakage, which can cause a Helmholtz resonance, or due to the pumping mode.

Figure 34 illustrates two attempts to make a best seal on the flat plate (modified with clay). The other curves in Figure 34 show the effects of leaks caused by eyeglasses. The "plastic frame" curve illustrates a Helmholtz resonance. There is sufficiently low damping so that the attenuation is negative. The plastic frames cause a 10 dB loss in performance. The "best seal" curves show the characteristic plateau below 200 Hz, and -12 dB/octave slope above 300 Hz, which is due to earcup pumping. The mechanical resonance in the pumping mode appears to be at about 200 Hz. Camp's curve[7] in Figure 30 shows a break point at about the same frequency. In the SPH-4, the pumping action limits the attenuation to about 15 dB at low frequencies.

The "best seal" earcup attenuation was measured at 3 sound pressure levels: 84, 94, and 104 dB SPL. There was no evidence of a non-linear response. This is the same result found by Forstall[41] for sound pressures up to 120 dB SPL.

Figure 35 shows a verification of the pumping theory. The upper curve shows the acceleration produced by 100 dB SPL sound field. A very light accelerometer was mounted to the earcup on the other side of the wall from the earphone. The lower solid curve shows the results of calculating the sound pressure in the earcup and determining the attenuation, using the measured acceleration and the earcup dimensions as parameters. The dashed curve is the measured attenuation.

Figure 36 shows how hair styles may influence earcup leakage. The dotted curve was made by positioning a woman's wig on the modified flat plate before placing the earcup.

Figures 34 through 36 should be compared to Figures 30 and 31 which show the attenuation obtained in the aircraft studied during this project. The comparisons show that a plausible explanation for the poor performance of the SPH-4 in the aircraft is either an improperly fitted helmet or interference from glasses or large amounts of hair. Additional experiments with human subjects are reported in the next section.

Another possible source of noise in the earcup is a variation of the pumping mechanism in which airframe vibrations are transmitted through the crewman's body to the head. A sound pressure is thus produced in the earcup due to the differential vibration of the head and the earcup. Figure 37 shows the results of a measurement in which ATC's modified flat plate with earcup in place was attached to a shaker and subjected to a vibration level of 0.1 m/s^2 (0.01 g), thus simulating a vibrating head. The bottom curve shows the measured sound pressure in the earcup.

In Appendix E, a mechanical model of the human body is described which predicts lateral head vibrations of up to 0.003 g in the frequency range near 90 Hz, assuming that the seat vibration reaches 1.5 g, the maximum level permitted by MIL-A-8870.[42] Assuming a linear relationship between vibration levels and sound pressure levels, Figure 37 shows that those vibration levels will result in sound pressure levels of about 90 dB inside an earcup. At frequencies above 200 Hz, much smaller maximum values of head vibration and sound pressure would be expected.

7.2 EXPERIMENTS WITH THE SPH-4 ON A REAL HEAD

The experiments described in the preceding section were continued by testing the SPH-4 with human subjects. In each case, the subject wore a medium-size SPH-4 helmet. The earcup cushions were in good condition although not quite as thick as those on the SPH-4 used for the tests which are described in Section 4. A miniature microphone was placed in the earcup at the face of the earphone, to monitor the sound pressure in the earcup. The cable was passed through a hole drilled in the left earcup. The hole was then sealed with modeling clay. The subject was seated four feet from a loudspeaker in an anechoic chamber. The subject faced the speaker with his left ear on the speaker axis. The ambient sound pressure was monitored at the "ear" of the helmet, one inch from the outside surface of the helmet. In each case, the helmet appeared to be of the correct size for the subject's head. There was no attempt to pad the inside of the helmet to improve the fit. The chin strap was pulled tight.

Figure 38 shows the attenuation obtained on a subject with fairly thick hair (an average "styled" haircut), with approximately one inch long hair in sideburns. About 11 dB of attenuation was obtained at 200 Hz when the subject did not wear glasses. However, when plastic frame glasses were worn (earpiece diameter of 1/8 inch), significant attenuation was obtained only above 300 Hz.

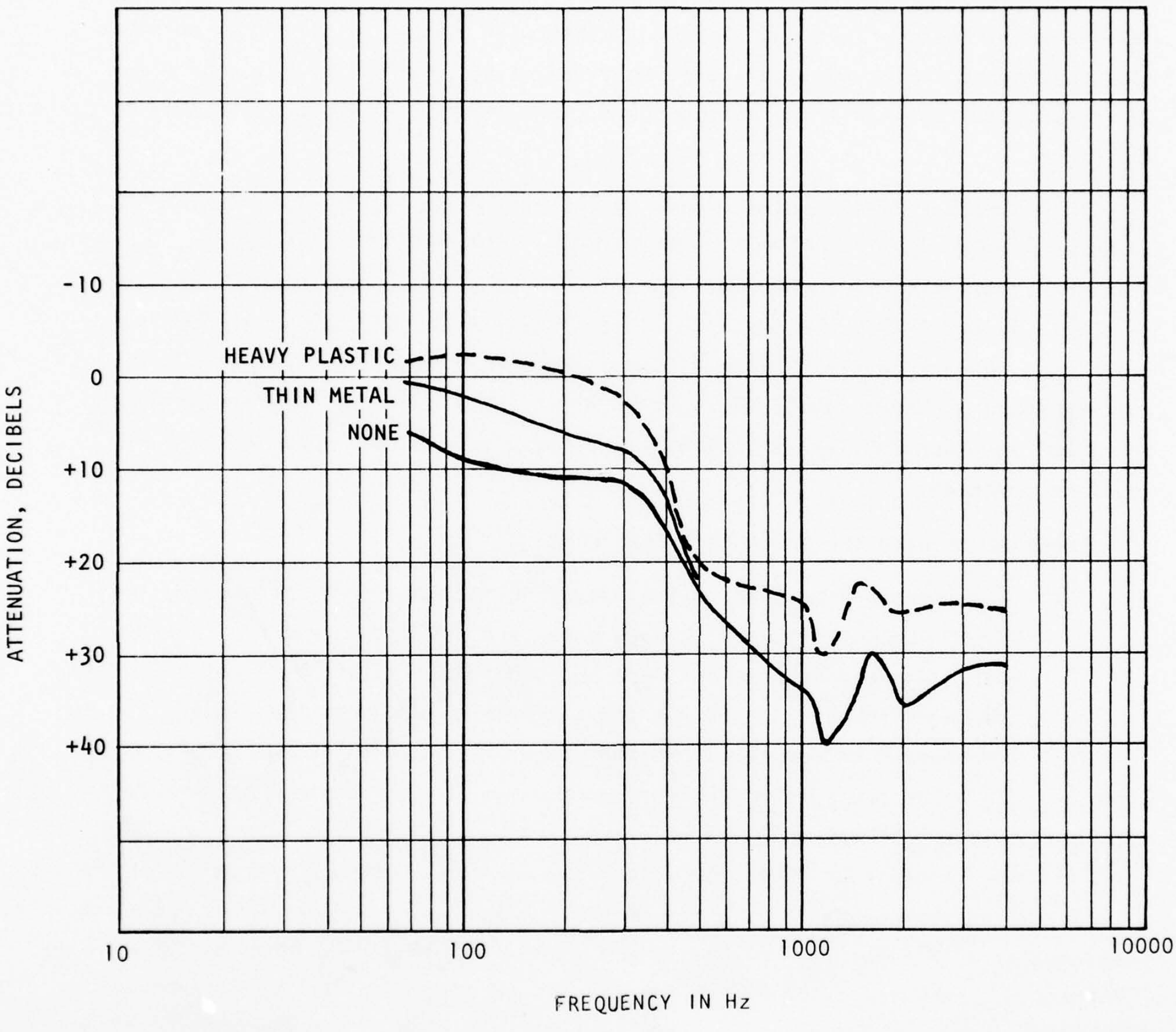


FIGURE 38 EFFECT OF GLASSES ON MALE SUBJECT
(JSS) WITH AVERAGE STYLED HAIR

Figure 39 shows that when a subject has very long, thick hair which covers the ears, no attenuation is obtained below 400 Hz. Nor is the attenuation improved very much by tightening the chin strap.

Although two other subjects were tested, both with relatively short hair, no attenuation curves were obtained that were better than the bottom curve in Figure 38. Various trials with the subjects indicated that those with shorter hair have a better potential for obtaining good attenuation at low frequencies, but that a considerable amount of adjustment of the cushions and chin strap, and placement of padding inside the helmet, may be necessary to realize that potential.

A questionnaire was sent to the five observers who wore the SPH-4 helmet during the data-taking in the aircraft. The answers indicated that all of the observers wore some kind of prescription glasses or sunglasses, a practice which is also common among the crew in these aircraft. The thickness of the earpieces (perpendicular to the temple) ranged from 0.04 inches to 0.125 inches. Hair styles ranged from moderate length (1/2 inch average) up to fairly long, similar to that of the subject of Figure 38. Sideburns were not prominent. An attempt was made to correlate the earcup attenuation which was obtained in the aircraft with the hair styles, dimensions of eyeglass frames, and technique of the observers. No correlation was found.

All of the observers adjusted or "worried" the earcups to make a better seal after donning the helmet. The chin strap was adjusted to be snug in every case. As a measure of the quality of the seal, four out of five observers felt that a significantly better seal could have been obtained by moderately pressing the earcups against the head with the hands.

The experiments of this and the preceding section indicate that the deficient performance of the SPH-4 in the aircraft (see Figures 30 and 31) can be accounted for in the region 50-300 Hz by the presence of acoustic leaks past the cushion due to a combination of less than perfect fit, and the interference of glasses and hair. The performance of the SPH-4 in the aircraft at higher frequencies cannot be fully accounted for, since Figures 38 and 39 show that at 1000 Hz and higher frequencies, attenuations of greater than 25 dB are obtained even with substantial leakage. Some possible reasons for the discrepancy are:

- o The results shown in Figures 38 and 39 are less applicable at higher frequencies since the measurements were not made in a spatially random noise field.

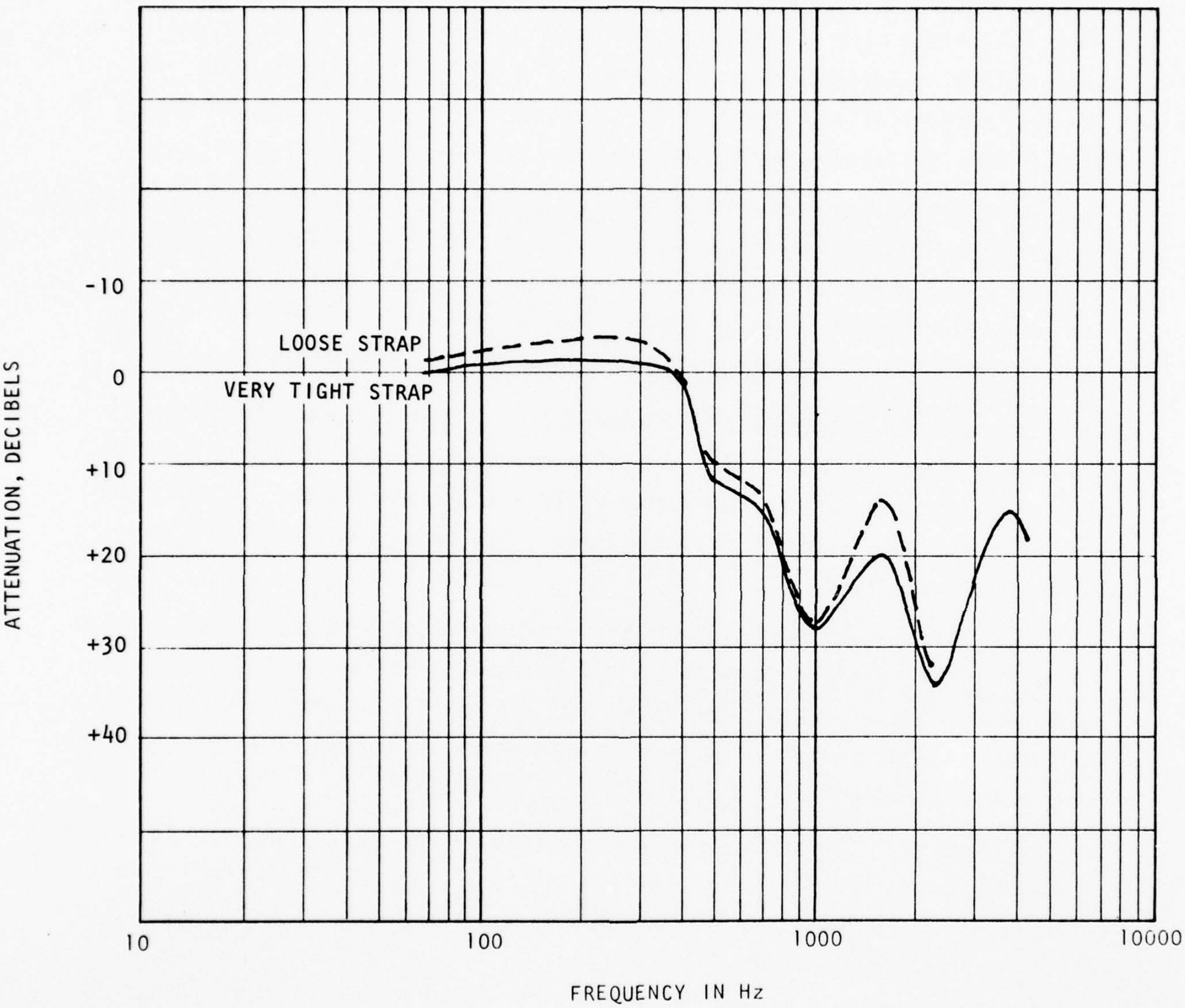


FIGURE 39 EFFECT OF VERY LONG, THICK HAIR ON MALE SUBJECT (JGC)

- Noise due to the tape recording process may be significant above 1000 Hz, because the range of the spectrum level of noise exceeds the dynamic range of the tape recorder (see Appendix B). In this case, the actual attenuations provided by the SPH-4 in the aircraft may well be as good as it is in the laboratory, at frequencies near and above 1000 Hz.

7.3 COMPUTER SIMULATION OF EARCUP PERFORMANCE

Definitive publications (e.g., Zwislocki,[36,37]; Shaw and Thiessen[38]) which describe mathematical analogs of earcups were published about 20 years ago. The equations in those publications were derived from schematics of electrical analogs of earcups. At the time of those publications, electronic digital computers were not available to aid analyses, so assumptions were made to simplify extraction of numerical values from complicated equations. For example, Zwislocki[36] examined the influence of earcup damping on earcup performance by assuming that the stiffness of skin is much greater than the stiffness of an earcup cushion; that is equivalent to considering an earcup on a rigid surface, which leads to conclusions which do not apply to an earcup on a real head. Zwislocki[43] combined flesh properties and cushion properties, and assumed that an earcup system is critically damped; that approach also does not provide an analysis of the sensitivity of earcup performance to cushion damping. Shaw and Thiessen[38] published a graph which showed the influence of cushion damping on earcup performance, but they neglected skin flexibility in deriving that graph.

Since there are no published results of exact calculations of the influence of earcup damping on earcup performance, we programmed a CDC 6600 electronic digital computer to perform those exact calculations. The results which are described in this Section are for the "pumping mode" only. It is assumed that all leaks have been eliminated and that transmission through the body is negligible. Appendix F describes electrical analogs and corresponding equations which were used in the studies which are reported here. That appendix also includes a listing of the FORTRAN IV computer program that was used, and typical tabular and graphical print-outs of the program are presented.

Figure 40 shows a comparison between transmission ratios calculated by means of the computer program which is described in Appendix F and transmission

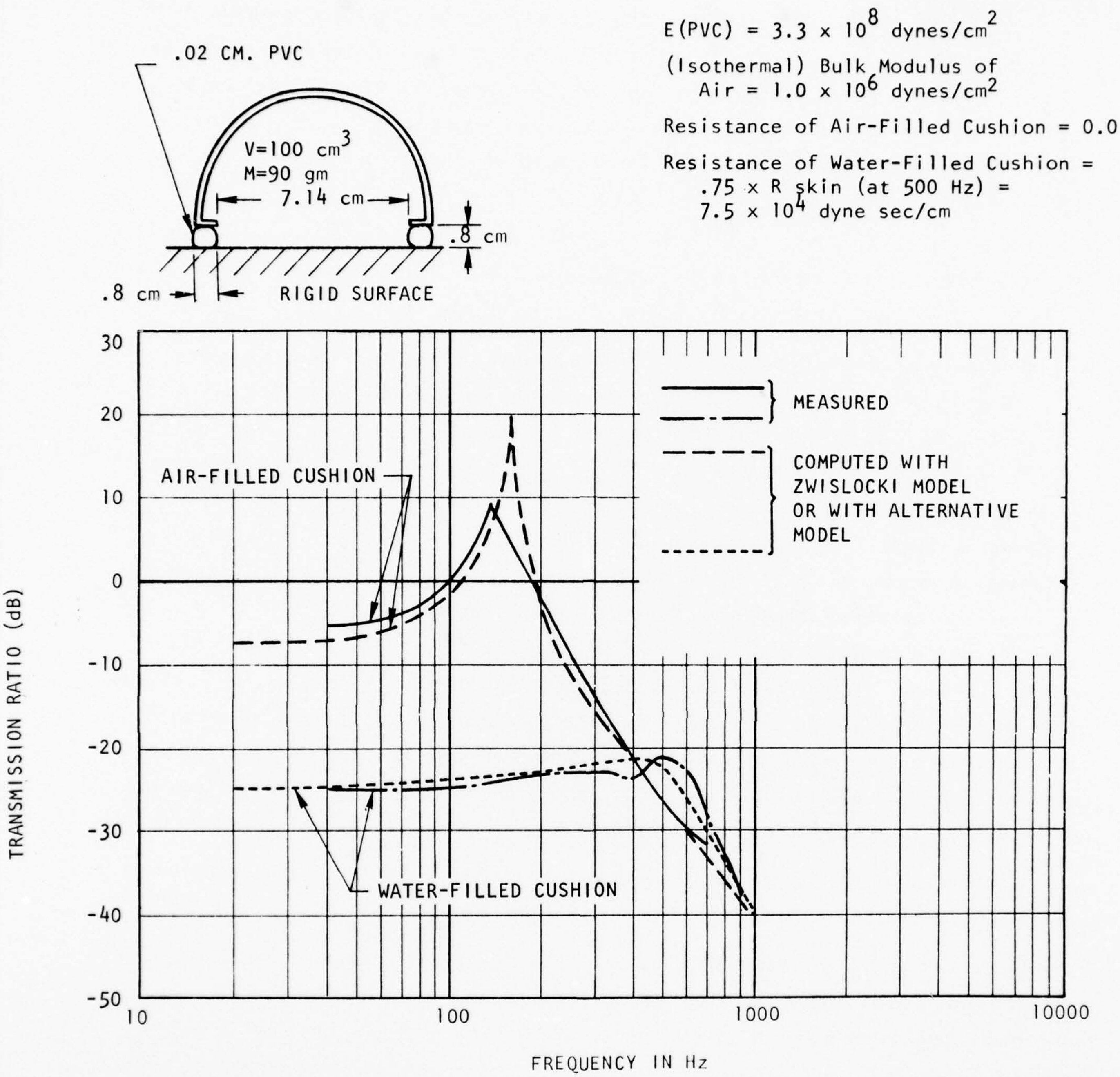


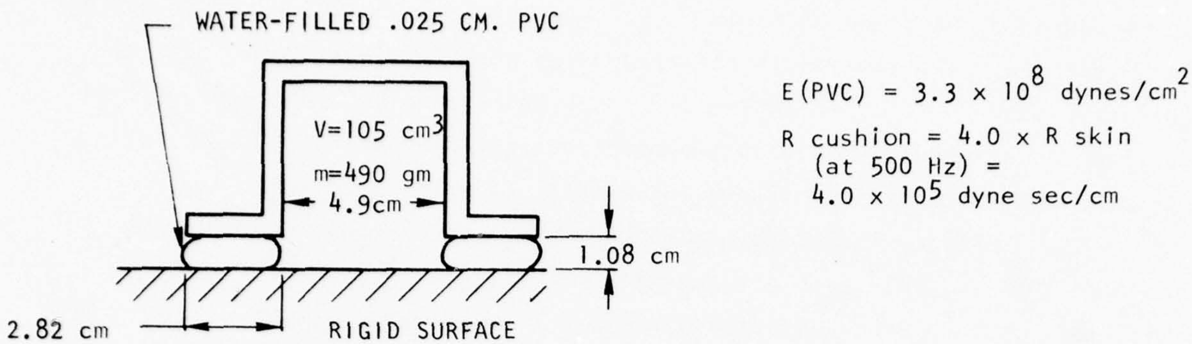
FIGURE 40. COMPUTED AND MEASURED TRANSMISSION RATIO FOR EXPERIMENTAL EARCUPS - EARCUP SHOWN IN FIGURE 8 OF SHAW & THIESSEN[38] ON A RIGID SURFACE

ratios measured by Shaw and Thiessen[38] for two test earcups which are described in their article. The two models referred to as the "Zwislocki model" and the "alternative model" are based on two different modes of displacement of skin by an earcup. Those modes and models are described in Appendix F. Matches between calculations and experimental results were obtained by using a value for the Young's modulus of polyvinyl chloride earcups equal to one-half of the value reported by Shaw and Thiessen[38] for static elongations. The matches for water-filled cushions were obtained by using a cushion resistance equal to 0.75 or 4 times the resistance of the skin around an ear, depending on the geometry of each cushion. In view of the high viscosity of skin, that may seem like a high value for the resistance of a water-filled cushion, but resistance depends on geometry and velocity fields as well as on viscosity. Much higher fluid velocities are established within a fluid that is confined in a small space than is generated in skin by earcup vibrations, so viscous losses can be higher in a confined low viscosity material than in an unconfined high viscosity material.

Figures 40 and 41 show good agreement between calculated and measured values of the transmission ratio of two particular earcups on a rigid surface. That agreement indicates that the geometric and material coefficients of the two subject earcups are appropriate. The "peaked" deviation of the calculated curve near 160 Hz for the air-filled cushion from the measured curve in Figure 40 merely indicates that air provides some cushion resistance; zero cushion resistance was assumed for calculations of the performance of the air-filled cushion.

The match between calculated and measured values of earcup transmission ratio is much better for the "Zwislocki model" than for the "alternative model" in Figure 42 . That indicates that the mode of deformation of circumaural skin by an earcup that was assumed for the Zwislocki model is more applicable than the mode of deformation that was assumed for the alternative model (see Appendix F). However, that conclusion is based on a single example; the mode of deformation depends on the stiffness of the air volume enclosed by an earcup, and it may depend on the configuration of an earcup and on contact pressure. Therefore, the question of which model is applicable to a given earcup at a given frequency and a given contact pressure should be recalled for each analysis.

Figure 42 shows measured values of transmission ratio which are greater than "Zwislocki" calculated values at high frequencies, which reveals less than expected "mass-law" performance.[38] The high measured values may be due to bone conduction, air leaks, surface waves in skin, inner ear impedance, or transmission of sound directly through earcup walls. Those factors should be included



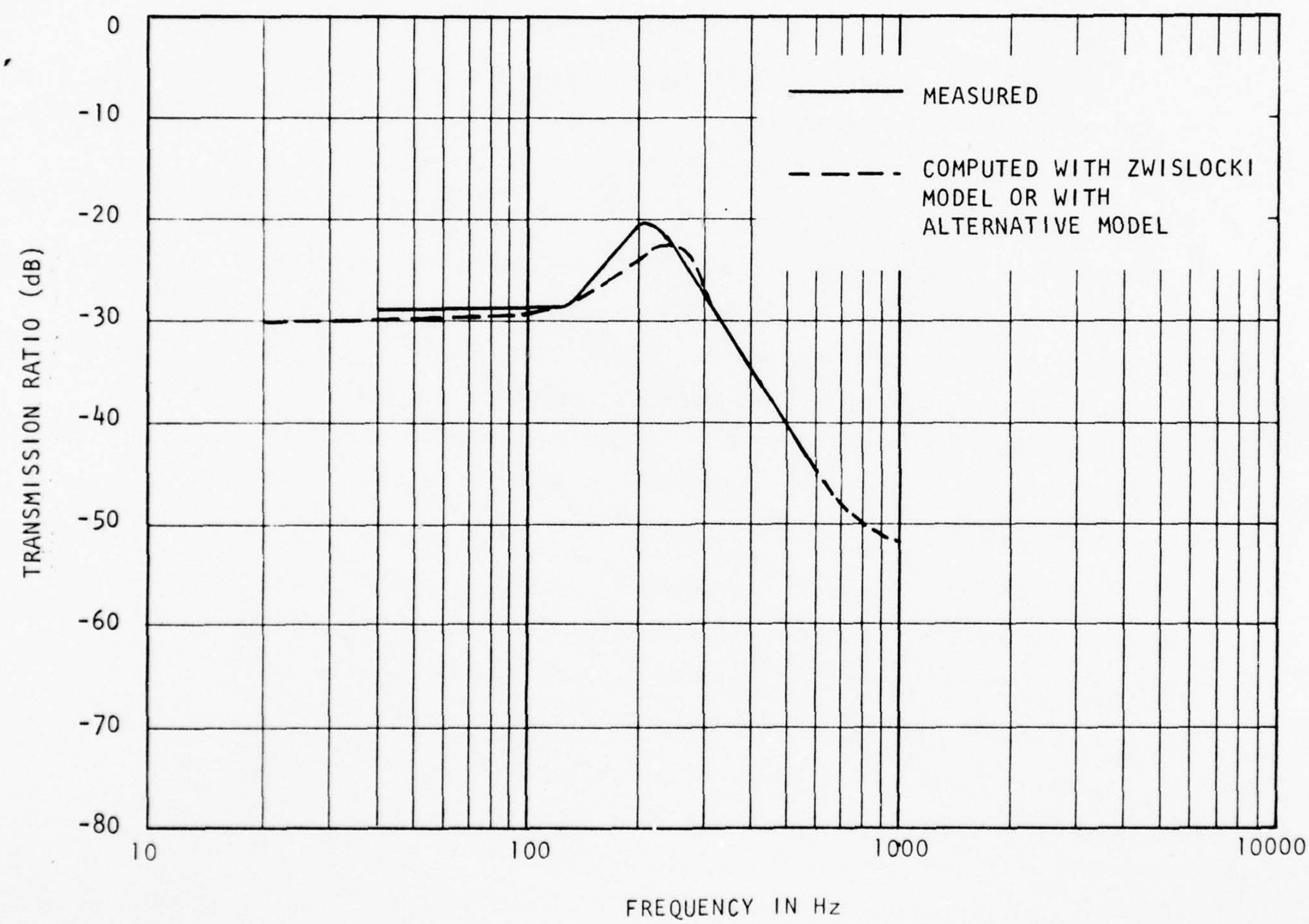
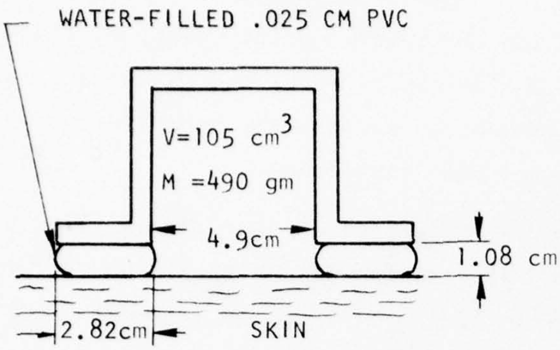


FIGURE 41. COMPUTED AND MEASURED TRANSMISSION RATIO FOR EXPERIMENTAL EARCUPS - EARCUP SHOWN IN FIGURE 11 OF SHAW & THIESSEN[38] ON A RIGID SURFACE



*E(PVC) = 3.3×10^8 dynes/cm^2
K Skin = 8.0×10^7 dynes/cm (Ref. 38)
Frequency-Dependent R Skin from Franke (Ref. 44) x 10 (Ref. 38)
R Cushion = 4 x R Skin (at 500 Hz) = 4.0×10^5 dyne sec/cm

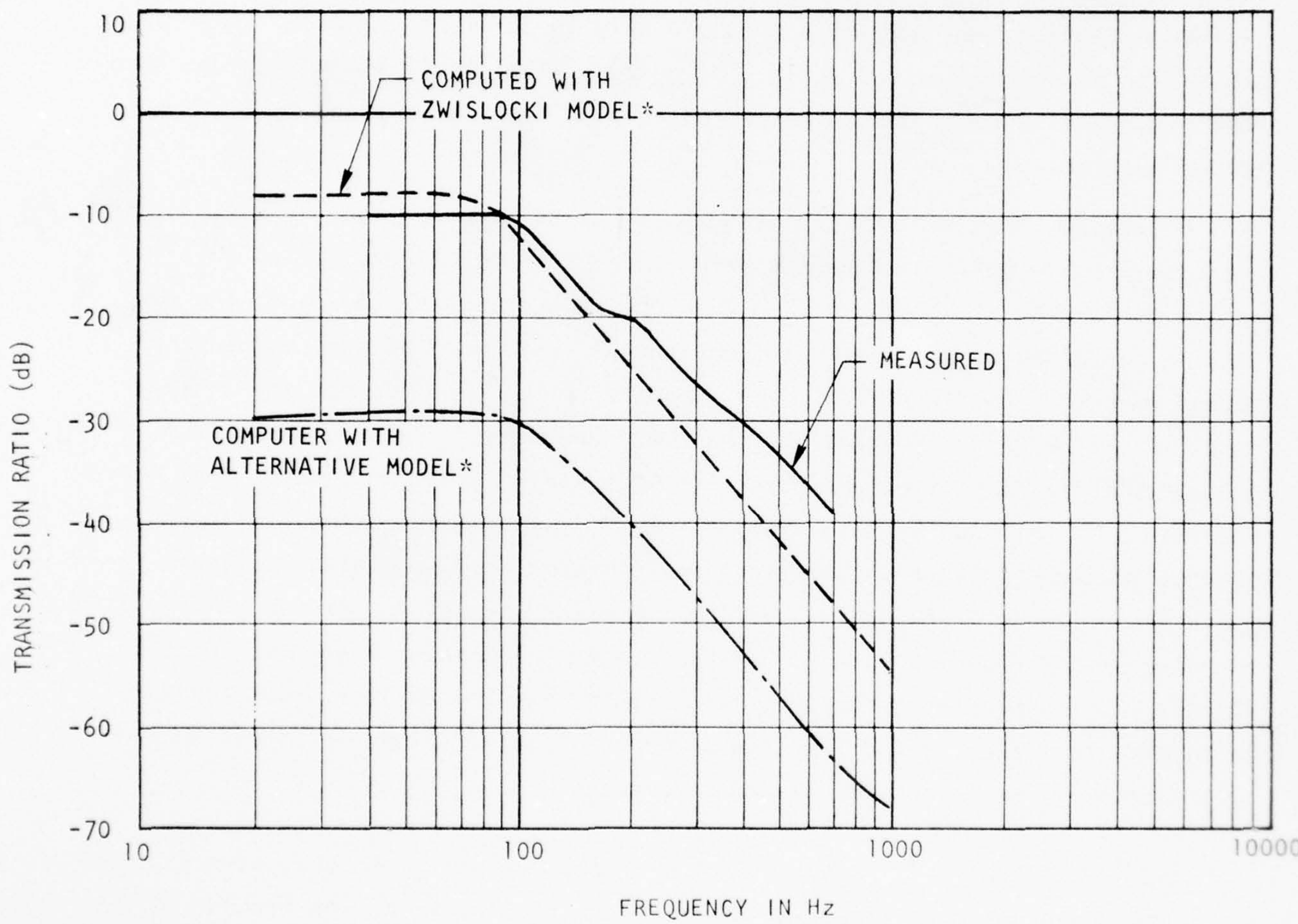


FIGURE 42.COMPUTED AND MEASURED TRANSMISSION RATIO VERSUS FREQUENCY FOR EXPERIMENTAL EARCUPS

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ANALYSIS OF NOISE IN US ARMY AIRCRAFT.(U)

NOV 78 A J BROUNS, R A ELY DAAB07-76-C-1746

UNCLASSIFIED ATC-94100/8CR-41 USAAVRADCOM-TR-76-1746-F NL

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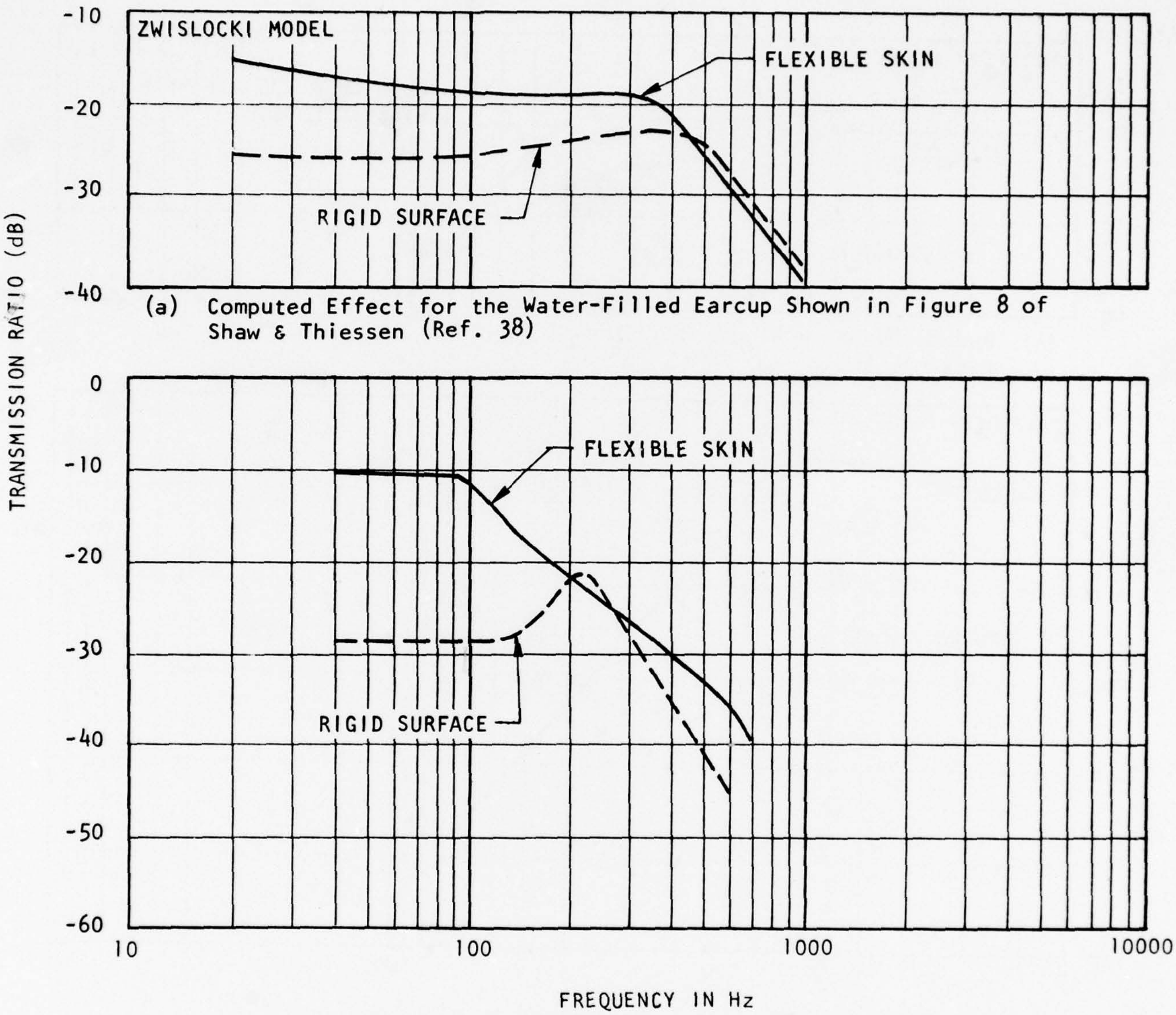
in future computer models. However, the agreement between the values of transmission ratio which were calculated with the Zwislocki model and measured values was judged adequate to justify using that model to explore the sensitivity of earcup performance to changes in cushion and skin resistance.

Figure 43 shows calculated and measured influences of skin flexibility on the transmission ratio of two experimental earcups with water-filled cushions. That figure shows that the influence of skin flexibility on the transmission ratio of an earcup with a liquid-filled cushion can be pronounced. Since that influence has not been investigated thoroughly in published studies, there is a question as to whether the designs of earcups with liquid-filled earcups have been optimized to take full advantage of damping that is provided by liquid-filled cushions.

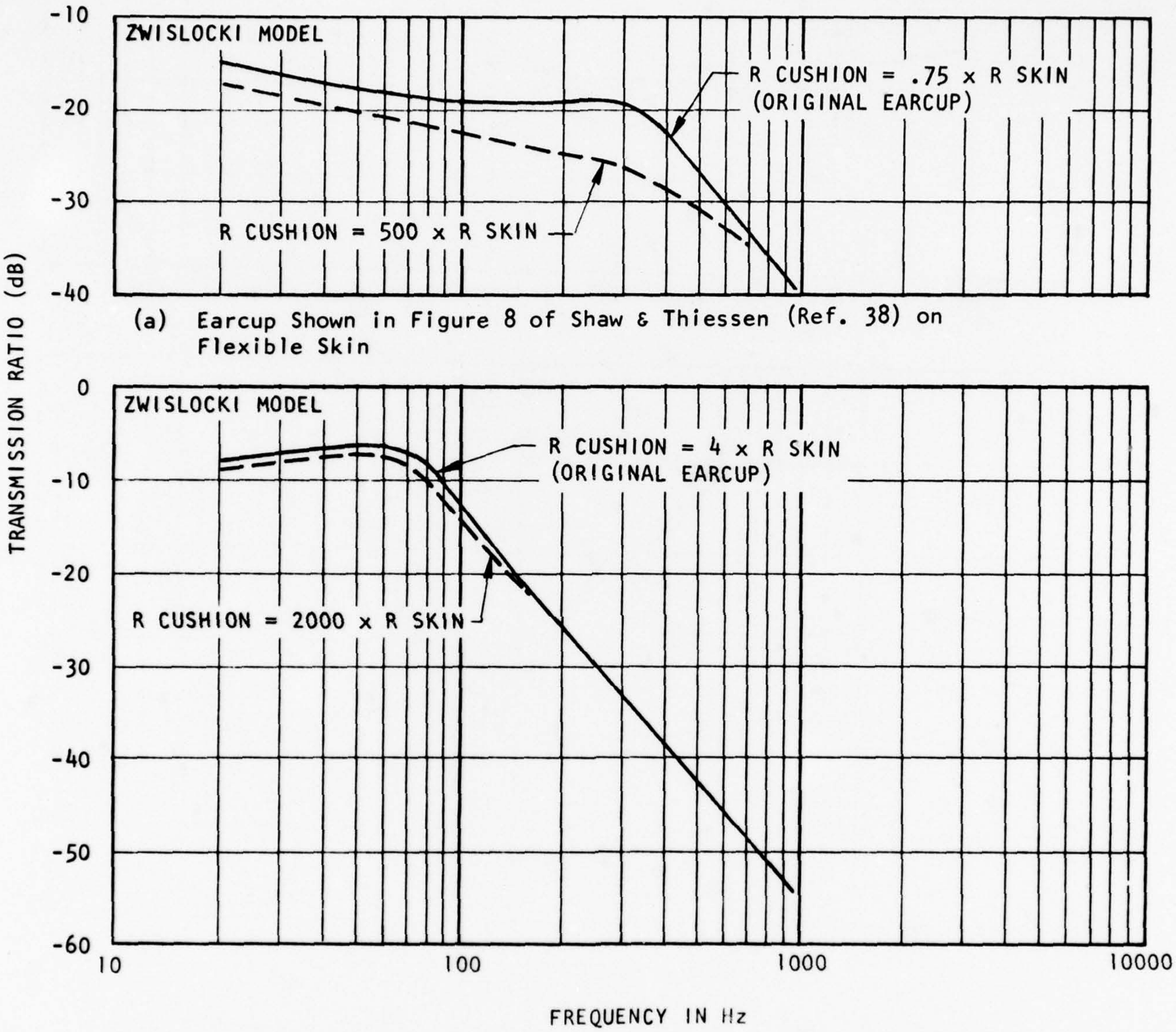
Figure 44 shows the results of computer calculations of the sensitivity of the transmission ratio of two experimental earcups with liquid-filled cushions to the mechanical resistance of the cushions. That figure shows that the benefits to be gained by increasing the mechanical resistance of earcup cushions depend on earcup configuration. The computer calculations do not show a large benefit for the two configurations that were analyzed. However, there is no assurance that the volumes and cushion stiffnesses of the two earcups that were analyzed were selected by experimenters to yield the optimum sensitivity to earcup resistance. Further mathematical and computer studies similar to those which are outlined in Appendix G will be necessary to define optimum configurations for earcups. The equations which are presented in Appendix G are very complicated; they are presented merely to illustrate that the optimum conditions are so complex that they defy definition by means of applications of intuition and trial-and-error variations of design parameters.

Shaw and Thiessen[38] reported no appreciable benefit when they substituted a 2.5 million centipoise syrup for water in the cushion of one particular earcup. However, they reported that the syrup could be molded, which means that it was actually a low-yield plastic solid, which does not meet the requirements for earcup damping. In addition, the viscosity of the syrup was much higher than typical optimum values that are indicated by cursory studies and the design of the test earcup system was not optimized to give the maximum advantage from filling of the earcup cushion with a viscous liquid.



(b) Measured Effect Reported by Shaw & Thiessen[38] for the Earcup Shown in Figure 11 of their Publication

FIGURE 43 EFFECT OF SKIN FLEXIBILITY ON THE FREQUENCY-DEPENDENCE OF THE TRANSMISSION RATIO OF EXPERIMENTAL EARCUPS



(a) Earcup Shown in Figure 8 of Shaw & Thiessen (Ref. 38) on Flexible Skin

(b) Earcup Shown in Figure 11 of Shaw & Thiessen[38] on Flexible Skin

FIGURE 44 COMPUTED EFFECT OF CUSHION RESISTANCE ON THE FREQUENCY-DEPENDENCE OF THE TRANSMISSION RATIO OF EXPERIMENTAL EARCUPS

Zwislocki[43] reported some improvement in the transmission ratio of a test earcup when the earcup cushion was filled with wax, but that improvement may have been due to associated changes in earcup mass or to changes in the transmission of sound directly through cushion walls.

Further mathematical and experimental studies are required to define fully the potential for improvements in earcup performance. The computer model should be expanded to include the effects of bone conduction, air leaks, surface waves in skin, and inner ear impedance.[37]

7.4 FIELD EXPERIENCES WITH EARCUPS AND OTHER EQUIPMENT ITEMS

At various times during the project, contacts were made by letter, telephone, and personal visits with medical and administrative persons in the military services, to learn more about equipment and operations. Additional contacts were made with technical persons in industry and DoD. In Section 11, there is a partial list of the persons contacted. In this Section, some of the comments made during these contacts are presented. This survey was not scientifically conducted; the comments are offered to stimulate further discussion and investigation.

A complaint from helicopter manufacturers and from military hearing conservation personnel alike is that air crewman defeat the noise control features that are built into the aircraft. This is another way of saying that the aircraft are not designed for the uses that are made of them.

Helicopters are several dB noiser, especially in the 100-300 Hz frequency band, if operated with doors open. However, as a practical consideration they are often operated thus to enable rapid egress.

Helicopters sent to combat regions are routinely stripped of acoustic padding because the padding not only bears a weight penalty, but also covers up critical hydraulic lines which must be inspected frequently for leaks. Manufacturers are allowed to meet MIL-A-8806[29] by retrofitting acoustic padding and other materials which usually are not compatible with combat conditions. In some cases, DoD will waive MIL-A-8806 for cost, weight, or other considerations. The rationale seems to be that aircraft may be allowed to be sources of noise that is well above human tolerance, if hearing protectors are capable of lowering noise levels to the tolerance level. With this situation, there is the danger that safety precautions will fail. This is exactly what happens if hearing protectors do not provide the expected amount of attenuation.

A variance of noise exposure measured inside earcups is primarily due to differences in sizing and fitting of cups to various personnel. Some personnel have low tolerance to the pressures of ear cushions and tight chinstraps. Some 70 percent of air crewmen inspected recently were not properly fitted, and others, although properly fitted, did not have the proper adjustment of crossbands and fasteners in the helmet. Different styles of hair and eye glasses also add to variances of noise exposures, and compound the problem of ascertaining exposure levels.

Considerable non-uniformity exists in the SPH-4 units procured by the services, in part because four different companies are now making them. The applicable specification does not regulate quality sufficiently to avoid large and important differences in the hardness of the earcup seals and the mastoid cups. Variations of this kind are known to affect the results of noise measurements in laboratories and are likely to be even worse in operational conditions where vibrations occur.

Some flight personnel use customized helmets and earcups. These may or may not be as good as issue, but at best they tend to defeat the purpose of monitoring and control.

Earcup seals become hard and brittle with age. Personnel realize this and try to get them replaced for their own protection. This is not always possible. In a recent case, a large group of flight personnel waited 11 months for new seals to be procured, and finally had to go overseas without them.

Persons who cannot tolerate earplugs suffer from sharing the intercom with those who do. Earplug wearers require higher volume settings, and this causes extra noise in the ears of the non-wearers.

There is controversy as to what degree of blame for the hearing loss problem must be placed on radio and intercom equipment in military aircraft. Some investigators feel that the intelligibility of the electronic communications is too low, and that the volume is often turned up to harmful sound levels in an attempt to understand transmissions. Others feel that this condition is ameliorated because flight personnel learn by experience to decipher the distorted speech sounds, and have little difficulty with them. Speech comprehension probably does improve with experience, but personnel may form bad habits with

their use of the volume control, or may even suffer some hearing damage, before the necessary experience is gained. This suggests that a "low-volume," pre-flight training program to gain this experience for personnel would be a good investment for a hearing conservation program.

8.0 SUMMARY OF HARDWARE PERFORMANCE AND FEASIBLE IMPROVEMENTS

8.1 CABIN NOISE

von Gierke[45,46] identified the dominant sources of helicopter noise to be: (1) engines, (2) transmissions, (3) rotational noise generated by tail rotors, and (4) vortex noise generated by main rotors, and he referred to methods for predicting those noise levels. Since then, the main advance in the technology of predicting noise levels generated by propulsion systems has been the computerization of calculations which are otherwise much the same as they were 20 years ago (for example, Ramakrishnan, et al., 1975).[47]

In the early days of helicopters, internal combustion engines were used, and unmuffled exhausts were a major source of noise.[45] Modern helicopters are powered by gas turbine engines, and inlets, turbine blades, and exhausts of those engines are major sources of helicopter noise. Methods for analysis and control of such noise are still being developed,[48-52] but some practical applications of those new methods have been successful.[53,54] Methods for predicting rotor noise have been known for decades, but only recently have computer iterations on design variables made it practical to control rotor noise by judicious choices of blade shape, rotor solidity, and rotor tip speed.[54,55] Faulkner[54] performed studies of the cost of noise reduction in intercity commercial helicopters, and concluded: "...good economic performance can be expected of relatively quiet future helicopters which have low tip speeds and high solidity rotors."

Although the technology for predicting and controlling noise from engines and rotors is available, the technology for predicting and controlling transmission noise (predominantly gear noise) is not so well developed. Moeller[56] provided a good qualitative discussion of the problem, but quantitative predictions have been developed only in the last few years,[57,58] largely due to the necessity for carrying out the required calculations on modern high-speed electronic computers. The mechanisms of generation of gear vibrations and conversion of those vibrations to sound still are poorly defined and poorly understood. Therefore, for the present, control of gear noise must be achieved largely by means of vibration isolation[59,60] and by enclosing[61] the offending gears.

The principles of noise control in helicopters have been known for decades. In 1957, von Gierke [45,46] provided spectra of noise within and external to helicopters, reported studies of noise reduction achievable with special structures, and offered criteria for selecting materials for noise control. He reported that there were no quantitative methods for predicting noise generated by structure-born vibrations, but he judged that such noise is less important than air-borne noise (including noise transmitted directly through structures).

A few years after von Gierke's summary, Franken and Beranek[62] provided some more details of methods for predicting and controlling noise within aircraft. They noted that the main problem with predicting noise levels within aircraft is proper evaluation of all of the various paths by which noise can enter a cabin (for example, sidewalls, windows, partitions, seats, ventilators). They presented methods for predicting noise levels and for predicting noise reductions provided by cockpit structures, configurations, and materials. They reported measured transmission losses for a typical aircraft fuselage, and they discussed some details of designing such structural components as window frames and baggage racks for noise control.

Schultz[61] summarized the principles of designing aircraft enclosures to attenuate sound as those principles were known a decade after Franken's and Beranek's [62] publication. Very little had changed during that decade.

Six years after Schultz's publication, the practice of designing aircraft enclosures is still about the same as it was when he published, and it is about the same as it was when von Gierke published two decades ago. The main advances in predicting responses of structures to sound have been: (1) finite element methods,[63] (2) statistical energy analysis,[64] and (3) wave propagation and periodic structure theory.[65] Those three developments were made possible largely by the increasing availability of electronic computers. Regardless of new predictive techniques, the practice of designing aircraft structures for noise control has changed little during the past 20 years.

Many measurements of noise levels within cockpits have been accumulated (for example, reference 3), but most of those measurements remain in private company files, or must be ordered from government publication offices. Available

measurements and calculations of noise in the interiors of aircraft have served to confirm principles and trends that were established 20 years ago. For example, Catherines and Mayes[66] reported measurements of noise within two propeller-driven light aircraft; those measurements showed that windows provided only 3 decibels noise reduction, and that leaks around door seals were a major cause of high interior noise levels. Such conclusions can be drawn from the simplest predictive techniques of 20 years ago. Measurements and calculations performed by Vought Corporation personnel also show that windows are the weakest link in the acoustical path to the interior of one commercial helicopter. Figure 45 shows measured and calculated noise reductions provided by the windows of one commercial helicopter. The agreement between the measured and calculated values is very good, indicating that there is nothing unusual about the helicopter fuselage, windows, or interior. It is unfortunate that the helicopter windows interact with the interior in such a way as to decrease the noise reduction provided by the windows at the frequencies at which transmission gear noise occurs. (For that particular helicopter, gear noise is transmitted through windows, rather than through overhead structures which separate gears from the interior.)

Just as the principles and techniques for predicting external noise levels and the reduction of those levels by aircraft structures have been known for 20 years, the principles of predicting the relationship between sound levels and vibrations of structures have been known for many years. The U. S. Air Force[67] reported many experts' contributions of responses of structures to sound. Cremer, Heckl, and Ungar[68] and Ver and Holmer[69] summarized methods for predicting vibrations of structures resulting from impinging sound, and they described methods for predicting sound levels resulting from vibrations of structures. The most important concept underlying those methods is that, for frequencies of practical interest in controlling helicopter noise, vibrating fuselage sidewall panels (that are not forced by air-borne sound) radiate sound to the interior of helicopters only because of reflections from the edges of the panels. It does no good to add rubbery damping materials to fuselage panels except for panels which are excited by air-borne sound and which resonate at a frequency of concern. Absorptive material must be added at the edges of panels that are excited by structure-born vibrations to achieve reductions of internal noise levels. Such intricacies led Jones[70] in his review article on damping treatments, and Arctander[71] in his review article on absorptive

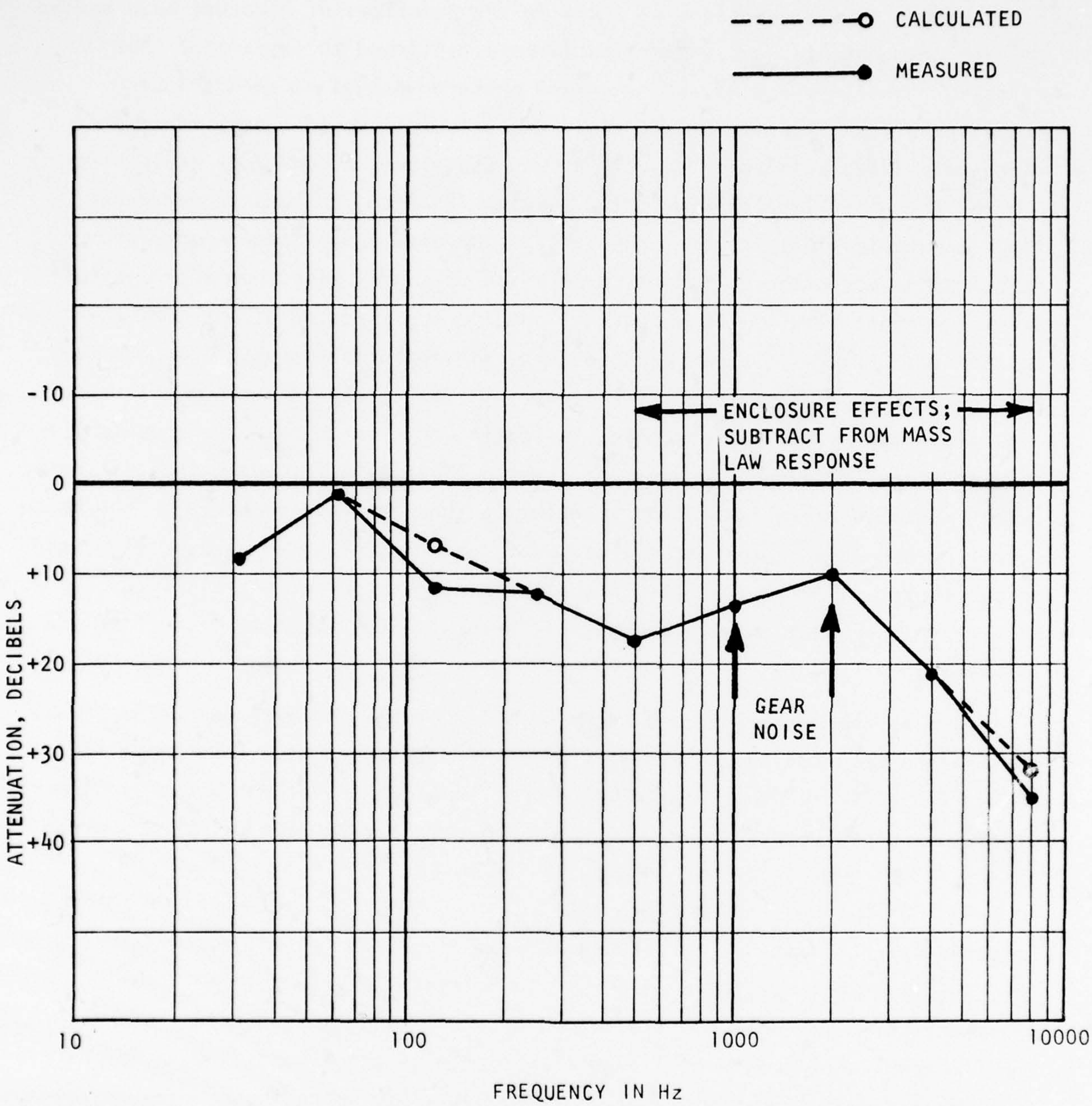


FIGURE 45. CALCULATED AND MEASURED NOISE REDUCTION DUE TO WINDOWS IN A COMMERCIAL HELICOPTER

materials to emphasize the need for precise tailoring of noise control methods to specific vehicles throughout design cycles. It is not enough to try to control noise and vibration by adding a few pounds of damping and absorptive material after an aircraft has been built.

A good example of the need for considerations of noise control early in the design of a helicopter was given by Sen Gupta.[72] He reported that overall cylindrical modes of entire fuselages dominate the acoustical behavior of aircraft structures at low frequencies which are the major problem with helicopters. That means that noise control should be considered when the size and shape of major frames for a helicopter fuselage are chosen. For intermediate frequencies, Sen Gupta[72] reported that fuselage panels and their stiffeners interact; that interaction should be optimized by proper trade-offs between panel design and stiffener design early in a design program. At higher frequencies, such as those where gear noise is predominant, the more usual quick-fixes, such as fiberglass, lead vinyl, and damping tape, can be helpful. However, at those high frequencies, the noise reductions provided by fuselage sidewalls and windows are strongly affected by interior geometry and materials,[62] so those factors also should be considered early in the design of a helicopter.

Efforts to quiet an HA-43B helicopter[73] are typical of current efforts. Engine noise, transmission noise, and rotor noise all are being considered in current efforts to quiet helicopters. When lowering of noise levels at the sources of noise is not considered adequate, attempts are made to modify structural responses and interior treatments to further lower internal noise levels. However, most efforts to quiet helicopters are directed at existing vehicles. There is not much hope of achieving much more than 10 decibels of quieting in that way. Noise control in helicopters must be approached as part of the systems optimization study at the outset of a design effort. Even with early involvement in design, the operational burdens of sound control may be too great. For example, a TREC[25] study showed that sound control amounting to one or two percent of the gross weight of an Army helicopter results in a decrease of about 10 percent in range. However, there were elements of retrofit philosophy in that study, and early involvement of acousticians in design might decrease the weight penalties for sound control.

A computerized search of all unclassified government reports that are related to aircraft noise and that were published during the last 10 years was completed for the authors of this report by the Defense Documentation Center. There are only a few reports which deal with control of noise within helicopters among the hundreds of titles and abstracts that were recovered by the computerized search. Only one discusses cost factors in any detail, and that discussion is focused on a computer model for unified noise, cost, and performance calculations, rather than on typical costs of noise control. The results of that literature survey agree with results of surveys of government and non-government literature which were conducted by the authors of this report. The results of these literature surveys indicate a low level of activity which is directed at controlling helicopter noise, especially if costs of noise controls are of interest. That low level of activity may be due to heavy operational and cost burdens that are indicated by cursory estimates (for example, Bowes[74]). A concerted research effort will be necessary to define those burdens in terms of overall systems development and in terms of realistic anticipated improvements in noise control techniques.

8.2 EARCUPS

Figures 46 through 50 show selected results of some previous investigations into earcup performance. In each case, Camp's real-ear measurement of the SPH-4 is plotted for comparison. Unless stated otherwise, the plotted attenuation will be assumed to have been measured using the real ear threshold method.

Figure 46 compares the real ear measurement, the specification[75] for the MK-1564( )/AIC earcup which is in the SPH-4, and a typical attenuation copied from Figure 30.

Figure 47 shows the bone conduction limits for attenuation.

Figure 48 shows the additional attenuation obtained when a V51-R earplug is worn underneath a "good" noisemuff. This muff is somewhat better than the SPH-4 earcup, perhaps due, for example, to a larger muff volume. Because of the effect of bone condition and other alternate paths, the muff and earplug attenuations are not simply added. Edwards, et al[76] found that industrial workers received about 15 dB less attenuation from earplugs at the workplace than was obtainable by careful fitting in the laboratory. This was attributed to using the wrong size earplugs and/or improper insertion.

Figure 49 shows that if high frequency sound enters the earcup, for example through a less than perfectly rigid shell, sound absorbing material in the cup is beneficial.

Zwislocki[36] assembled an experimental earcup in an attempt to reach what he considered the practical limit for attenuation. Figure 50 shows the attenuation obtained. The cup was very rigid. The cushion was filled with a malleable wax so that it conformed to the head, and also provided a large mechanical impedance at audio frequencies. The cup volume was rather small, apparently about 15 cm^3.

A comparison of Figures 47 and 50 shows that Zwislocki's practical limit is determined by bone conduction above about 700 Hz, and by earcup pumping below 700 Hz. Zwislocki felt that, within practical limits, the effect of pumping is not greatly affected by earcup size. This would especially be the case where the earcup must fit under a helmet, where increased volume is obtained by increasing the cross-sectional area of the earcup rather than the depth. If the cross-sectional area increases, the pumping force and the earcup volume increase at the same rate (see Appendix F). Other parameters being equal, the attenuation is not changed.

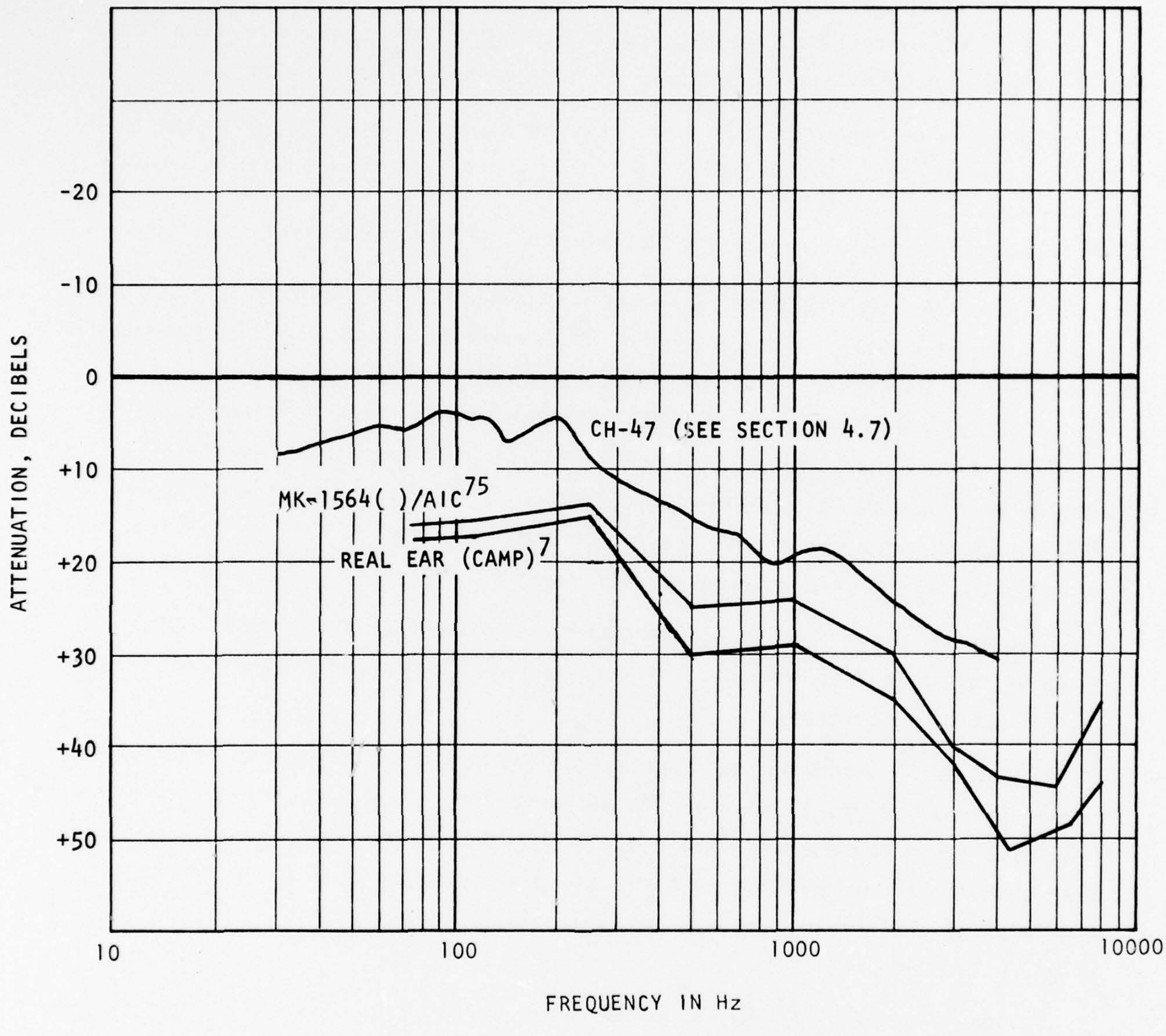


FIGURE 46. SPH-4 EARCUP ATTENUATION

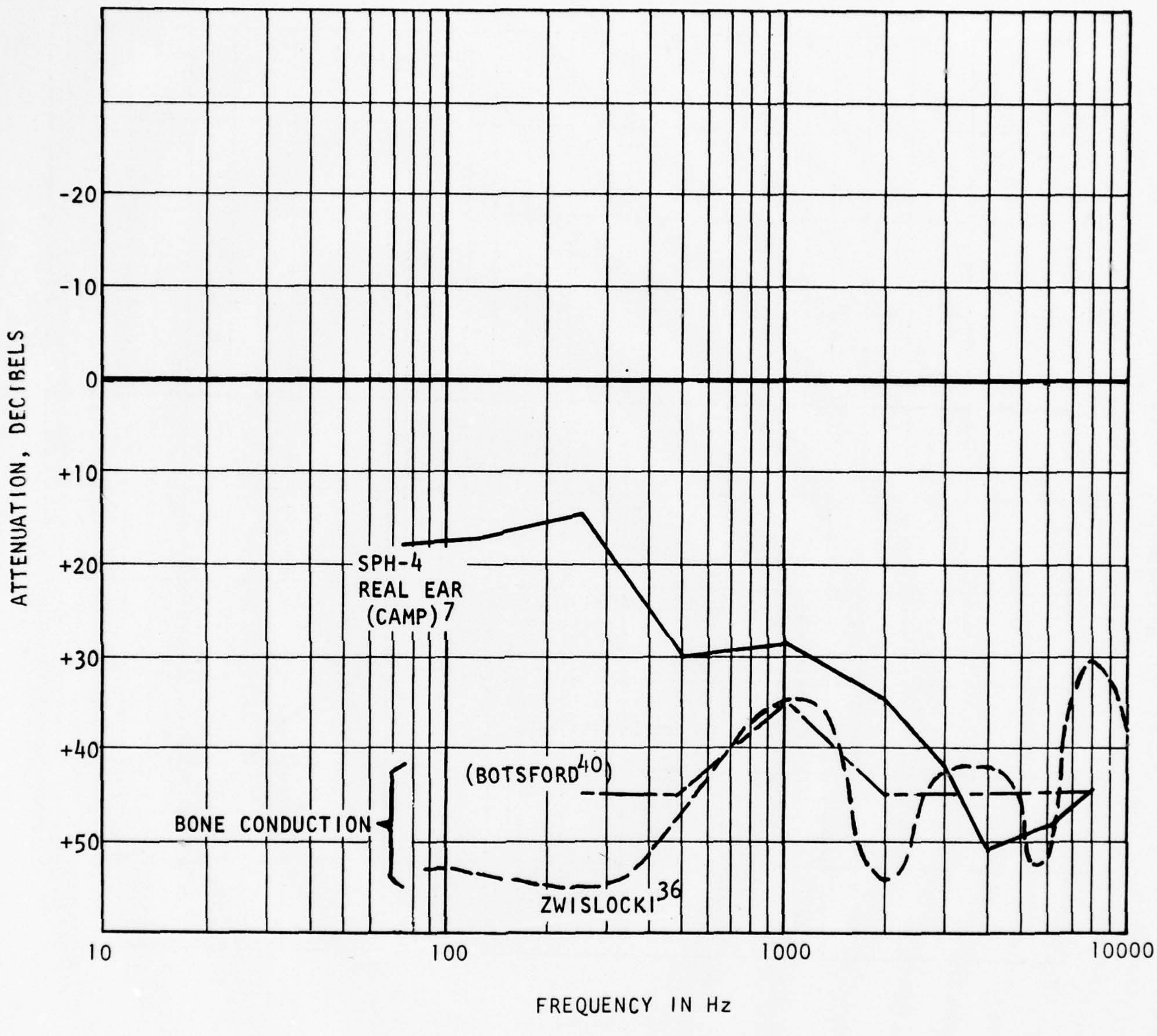


FIGURE 47. LIMITS TO EARCUP ATTENUATION (BONE CONDUCTION)

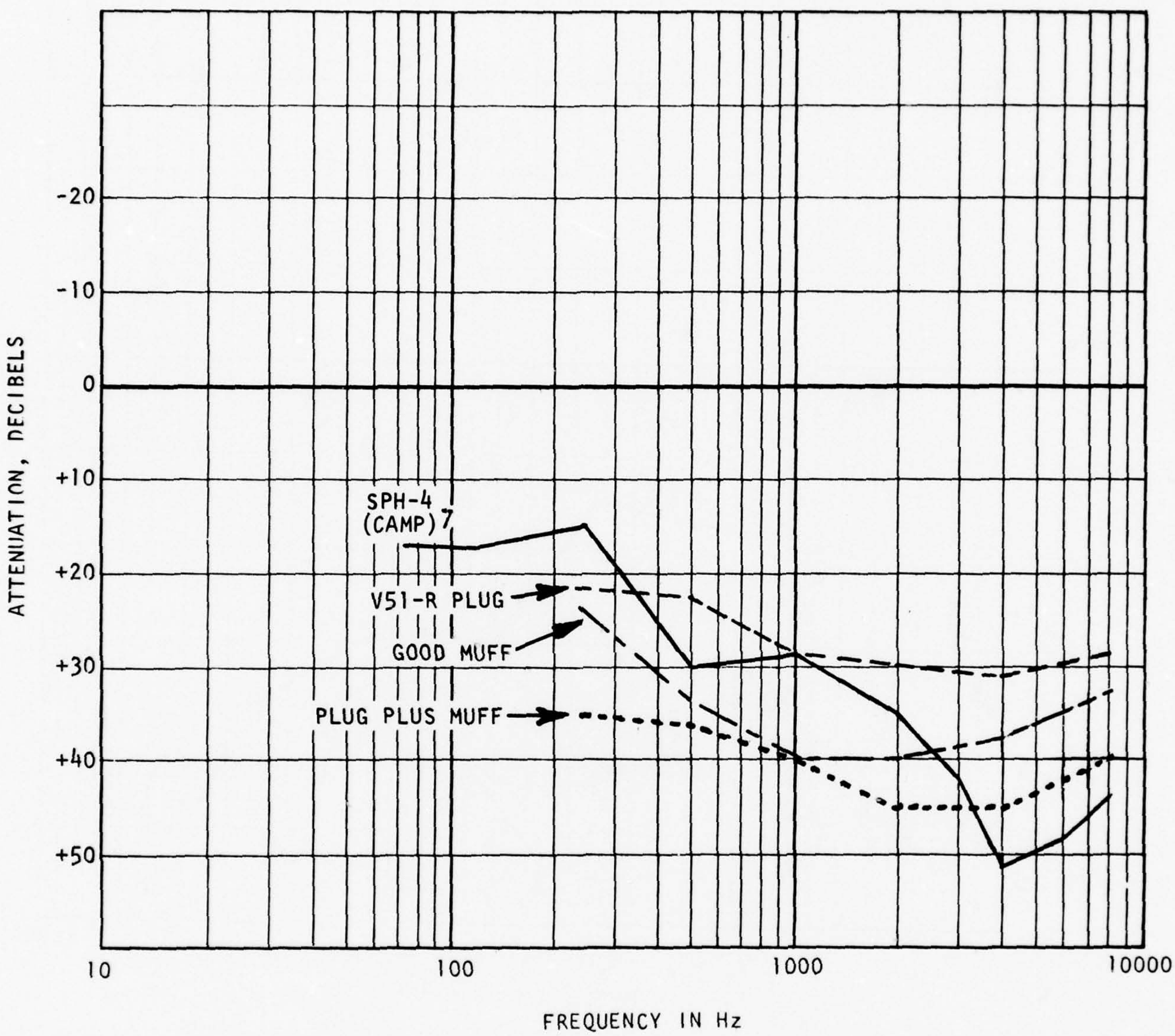


FIGURE 48. ATTENUATION OF EARCUPS AND EARPLUGS (BOTSFORD[40])

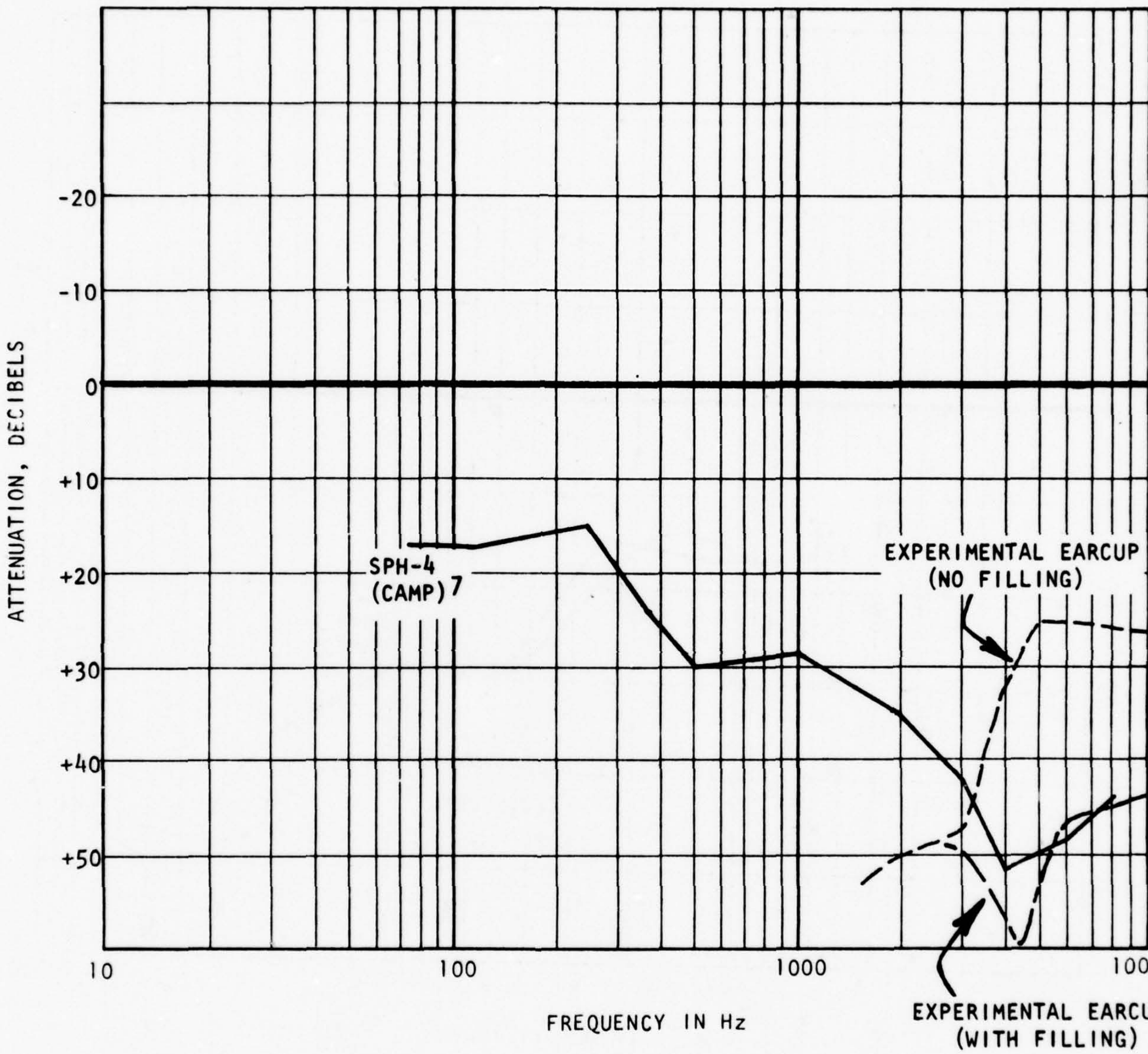


FIGURE 49. ATTENUATION OBTAINED BY FILLING EXPERIMENTAL CUP WITH SOUND-ABSORBING MATERIAL, ISOCYANATE FOAMED PLASTIC (SHAW AND THIESSEN[39])

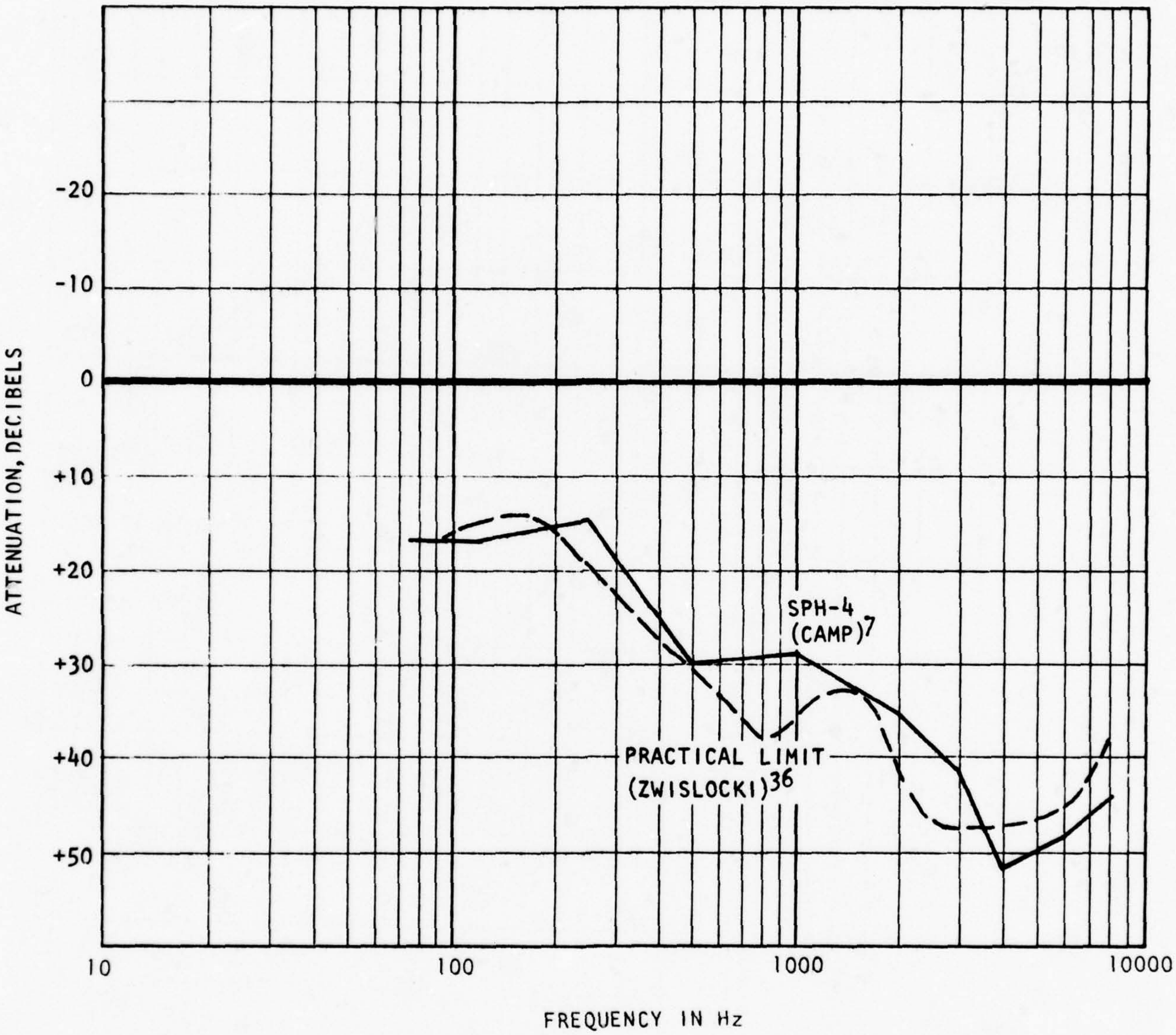


FIGURE 50. RIGID CUP WITH WAX-FILLED CUSHION (ZWISLOCKI[36])

The SPH-4 earcup was found to hold about 93 cm^3 of water with the cushion not depressed. Over the ear, the volume would be somewhat less.

Several investigators have attempted to modify the cup structure to obtain more attenuation. Shaw and Thiessen[38,39] made theoretical studies, followed by experiments on earcups in which the inside volume is partitioned. The two cavities thus formed are connected by an acoustic impedance, typically an acoustic resistance. At low frequencies, where the pumping mode is dominant, the cavities are acoustically connected providing a large volume for good attenuation. At speech frequencies, the cavities are acoustically isolated so that the earphone which is placed in the inner cavity can produce the required sound pressure without excessive power demands.

The two cavity experimental work was continued by other experimenters such as Rosenheck et al[77,84] who built and tested earcups of this type, some of which were designed to fit into flight helmets. Bauer and DiMattia[78] studied an earcup in which the two cavities were connected by paralleled resistance and inertance, in an attempt to control the troublesome acoustic resonances which appear at the transistion between the low frequency mode of operation (connected cavities) and speech frequency operation (isolated cavities). To summarize this work: the frequency response and attenuation characteristics of experimental models of two-cavity earcups have verified the theoretical models from which they were developed. There is a problem in interpreting the attenuation data because of the different test methods used by different investigators, who sometimes use flat plate couplers, sometimes manikin heads, and sometimes real-ear threshold methods. There is no clear evidence that two-cavity earcups, when designed to be compatible with U. S. Army systems, provide better attenuation than well maintained modern earcups already in the U. S. Army inventory, such as the SPH-4. Of course, if the system is not limited by the power handling capability of the earphone, two cavities of the type described here provide no advantage over a large single cavity.

The reports by Rosenheck, et al, also describe some experiments with earcups which are rigidly yoked together across the head, or by means of a specially designed, rigid helmet. The purpose is to block the earcup pumping. Experiments show that when a sufficiently rigid connection can be accomplished, a major improvement in attenuation of up to 20 dB is obtained at low frequencies.

Until the development of modern foam-filled ear cushions, earcups with liquid-filled cushions provided superior attenuation. Today, the better foam-filled cushions appear to be nearly as good. Forstall[41] shows an attenuation curve in which a modified APH-6A helmet with liquid seal is about 4 dB better than the helmet with a foam seal. The SPH-4 provides about the same performance as the modified APH-6A with liquid seal. However, the discussion in Section 7.3 suggests that further experiments with liquid seals may be fruitful, particularly if the viscosity of the liquid is optimized.

There have been several investigations of active ear defenders which cancel noise in the earcup. A non-feedback technique was investigated by Meeker.[79] In this system, noise is picked up by a microphone outside the earcup. The microphone signal is then adjusted for phase and amplitude and delivered to the earphone. DiMattia and Love[80] investigated a non-feedback technique in which the sensing transducer was an accelerometer mounted on the earcup. Several dB of extra attenuation was achieved in a limited frequency band.

Meeker[79] and Malme, et al.[81] investigated a negative feedback method in which the microphone is placed in the earcup. Malme, et al also investigated a modified negative feedback system in which the feedback signal is delivered to an inertial force generator located on the outside of the earcup.

The feedback schemes which used the internal microphone were capable of 5 to 7 dB of extra attenuation at frequencies up to 250 Hz.

Leaks past the ear cushions pose a problem for all types of active systems for the following reasons:

- o The power handling requirements for the amplifier and earphones are much greater when a leak is possible.
- o A leak changes the phase response of the earphone - earcup system potentially causing oscillation in the feedback system, and loss of cancellation in the non-feedback system.

Feedback systems which use an internal microphone must be designed so as not to cancel speech transmissions.

Various attempts have been made to change the shape of the ear cushion for better performance. Malme, et al[81] tried a cushion which contacts the head above the ear but below the hairline, to obtain a better seal. In another USAECOM-funded project, a cushion was designed in which the volume change due to earcup pumping was compensated by an opposite volume change due to radially-outward flexure of the cushion.[82]

The best earcup real-ear-threshold attenuation values reported by various investigators for "practical" earcups and helmets tend to fall along the same curve on an attenuation vs. frequency plot. By "practical" is meant modern earcups already in the U. S. Army inventory, or earcups which have reached a stage of development where they have been essentially shown to be dimensionally compatible with Army systems. The helmets include the SPH-4, various helmets measured by Forstall,[41] and others. When properly manufactured, fitted, worn, and maintained, the SPH-4 and similar helmets provide about as much attenuation as can be obtained from any available helmet. The SPH-4 system includes not only the earcup and cushion, but the webbing restraints and under-the-chin strap which are essential to its performance. The SPH-4 earcup is stiff enough so that local flexure is not a significant problem. Flexure may contribute to residual sound leakage at high frequencies; however, the main problem is below 1,000 Hz.

The results described in Section 4, Figures 30 and 31, and in Section 7 show that too much of the performance of the SPH-4 is lost in the aircraft, due mostly to leaks around the cushion.

The following list summarizes various ways in which helmet performance could be improved at frequencies below 1,000 Hz.

1. Increase the volume of the earcup by increasing its depth without sacrificing rigidity. This is a proven method, but requires that the helmet shell be substantially widened. This improvement would be effective against both earcup pumping and leakage.

2. Significantly increase the mass of the earcup shell to move the system resonance from around 200 Hz to well below 100 Hz. This is a proven method but the increase in helmet mass is a drawback. It would not be effective against leakage.

3. Rigidly connect the earcups together. The effectiveness against earcup pumping is proven but the feasibility of a practical mechanical design is not proven. It would not be effective against leakage.

4. Further develop ear cushions with optimized stiffness and/or damping, including those which compensate the volume change due to pumping, without compromising the ear cushion seal. They must provide acceptable comfort, and be manufacturable. They would not be effective against leakage.

5. Further develop active noise-cancellation systems including adaptive systems which could respond to changing phase conditions in the earcup. This is a hypothetical development requiring considerable signal processing power.

8.3 MICROPHONES

Figure 51 shows the frequency response of an M-87 microphone for both close and distant sources. The distant-source curves are shown for various orientations of the microphone with respect to the speaker axis. The speaker to microphone distance is 6 feet. The close-source curve is made at a distance of 1/4-inch. These measurements are made according to the method described in MIL-M-26542A[6] using a sound source constructed according to U. S. Air Force Drawing 58B12627 (30 June 1958). The difference between the close-source response and the 0°, 180° average response is the noise immunity. The noise immunity is plotted at the bottom of Figure 51. The noise immunity which is about 9 dB at 1000 Hz, is probably typical of M-87's in good condition.

Measurements of several M-87 microphones made at various times at ATC suggest that, due to hard use and aging of components, the noise-immunity may vary considerably among units that have been in service.

A number of alternative noise-cancelling microphones have been developed over the past 15 years, and some novel approaches have been explored for making microphones which are immune to noise. A major difficulty in developing improved

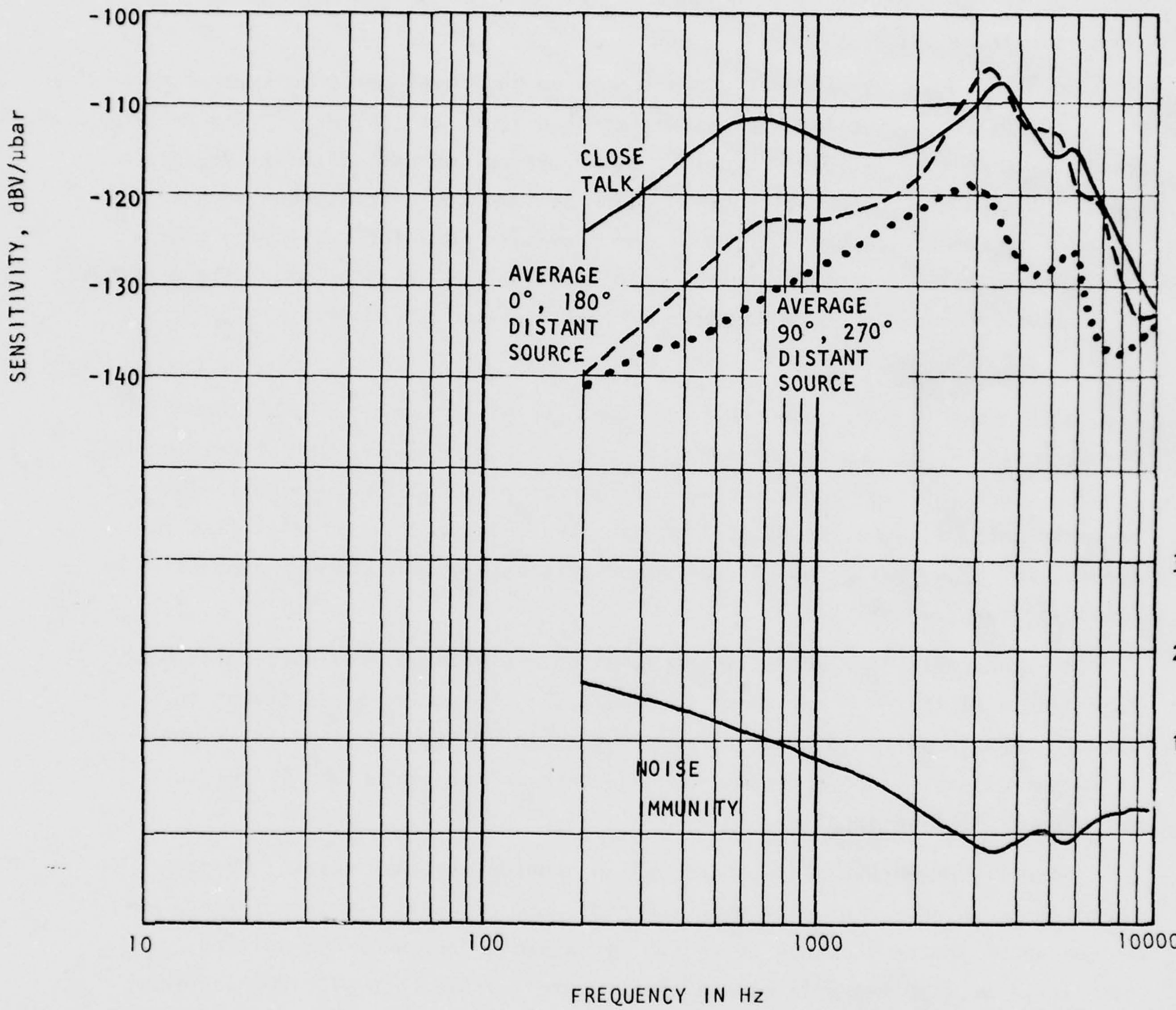


FIGURE 51. RESPONSE OF M-87 MICROPHONE, 5 Ω LOAD RESISTOR

dynamic and magnetic microphones is the requirement for good noise-immunity--which demands accurate, stable, acoustic components--along with a simultaneous requirement for operation over a range of altitudes, and operation after immersion in water.

The U. S. Army has in past years sponsored the development of several microphones which have noise immunities greater than 10 dB at 1000 Hz.[83] The M-93/AIC, developed in the early 1960's under U. S. Air Force Contract 30(635)18989, is a small magnetic microphone which has good noise immunity. It was not adopted for military or commercial use. There was no provision made for protection against immersion in water and other environmental hazards such as dropping. The assembly is precisely tuned, so there may be a problem of manufacturability.

More recently, piezoelectric and electret microphones have been developed. Figure 52 shows the response and noise immunity of a piezoceramic microphone.[85] The directivity pattern is a near-perfect cosine. The degree of noise-immunity is not susceptible to manufacturing tolerances or aging of components. The noise-immunity is about 14 dB at 1000 Hz. The response is virtually flat in the speech range; tailoring of the response is easily done to obtain other response characteristics.

Noise-cancelling electret microphones have also been developed which have performance similar to that shown in Figure 52. The primary constraint on use of piezoelectric and electret microphones in U. S. Army aircraft is one of compatibility, since these microphones have an integral preamplifier to which power must be supplied.

Recently developed microphones, which provide at least several dB of improvement in noise-immunity over the M-87, are probably close to the maximum noise-cancelling performance which can be obtained from noise-cancelling (gradient) microphones. It may be that future improvements will develop from current work in digital signal processing of speech.

8.4 PERFORMANCE TRADEOFFS

The durations of exposure of helicopter occupants are set by mission requirements. Since that parameter is fixed, overall dBA level is the only other parameter which can be controlled to reduce risks of hearing damage. If no

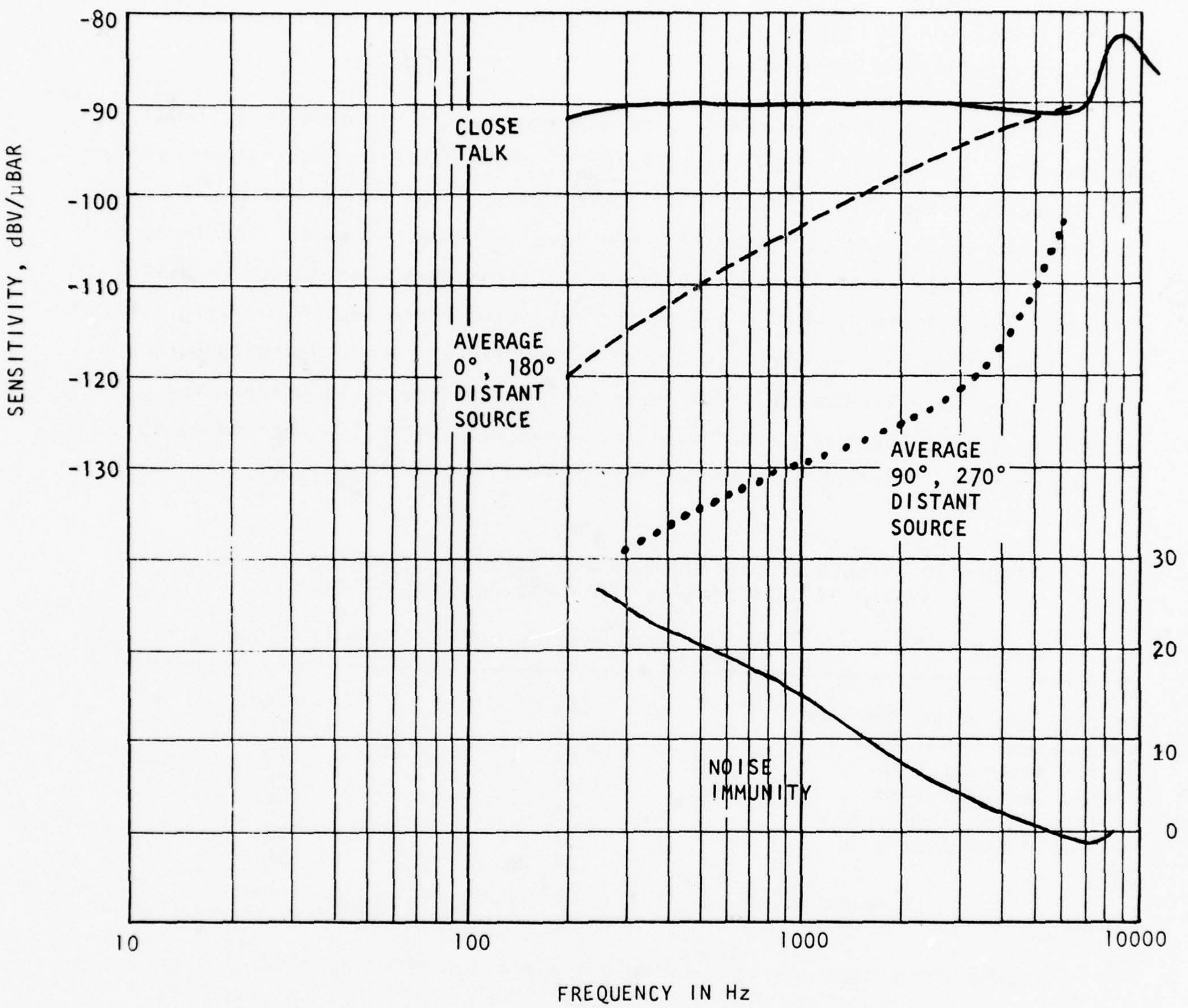


FIGURE 52. RESPONSE OF PIEZOCERAMIC NOISE-CANCELLING MICROPHONE, 150 Ω LOAD RESISTOR

other changes in a communications system are made, reduction of gain settings often will result in unacceptable intelligibility of radio voice messages. If intelligibility can be significantly improved for a given dBA noise level, then gain settings can be reduced without any decrease in the original acceptable value of intelligibility.

The intelligibility of radio voice messages can be improved in at least three ways: (1) reducing the transmission of cabin noise through earcup walls, (2) reducing noise that originates at a microphone or in an electrical/electronic transmission path, and (3) increasing the level of speech sounds. The first two actions will result in lower dBA levels. Although the third action will increase overall dBA levels slightly, the resulting increases in intelligibility more than offset the increases in overall sound level. The computer program for calculating articulation index (Appendix D) was used to illustrate the effect of such changes on sound levels measured within OV-1D number 69-17005 during descent. Table 8 is a summary of the results of that study.

TABLE 8
CALCULATED INFLUENCE OF CHANGES IN THE OV-1D NO. 69-17005 COMMUNICATION SYSTEM ON ARTICULATION INDEX AND ON SOUND LEVEL

ACTION	ARTICULATION INDEX	OVERALL SOUND LEVEL (dBA)
*Microphone noise down 3dB	.44	75
*Microphone noise down 6 dB	.47	74
Voice level up 3 dB	.46	77
Voice level up 6 dB	.51	78
Earcup noise down 3 dB	.46	76
Earcup noise down 6 dB	.51	76
None	.40	76

* Noise picked up at the microphone

Table 8 shows that the most efficient means for reducing risk of hearing damage is to increase earcup attenuation of cabin noise. The resulting increase in articulation index, with no accompanying increase in overall sound level, would allow a considerable reduction of gain settings and overall sound level before the value of articulation index would fall below the original value for the unmodified equipment.

Figure 53 shows the average earcup attenuation obtained in UH-1H #71-20254 compared to a laboratory measurement of attenuation obtained by Camp[7] for the

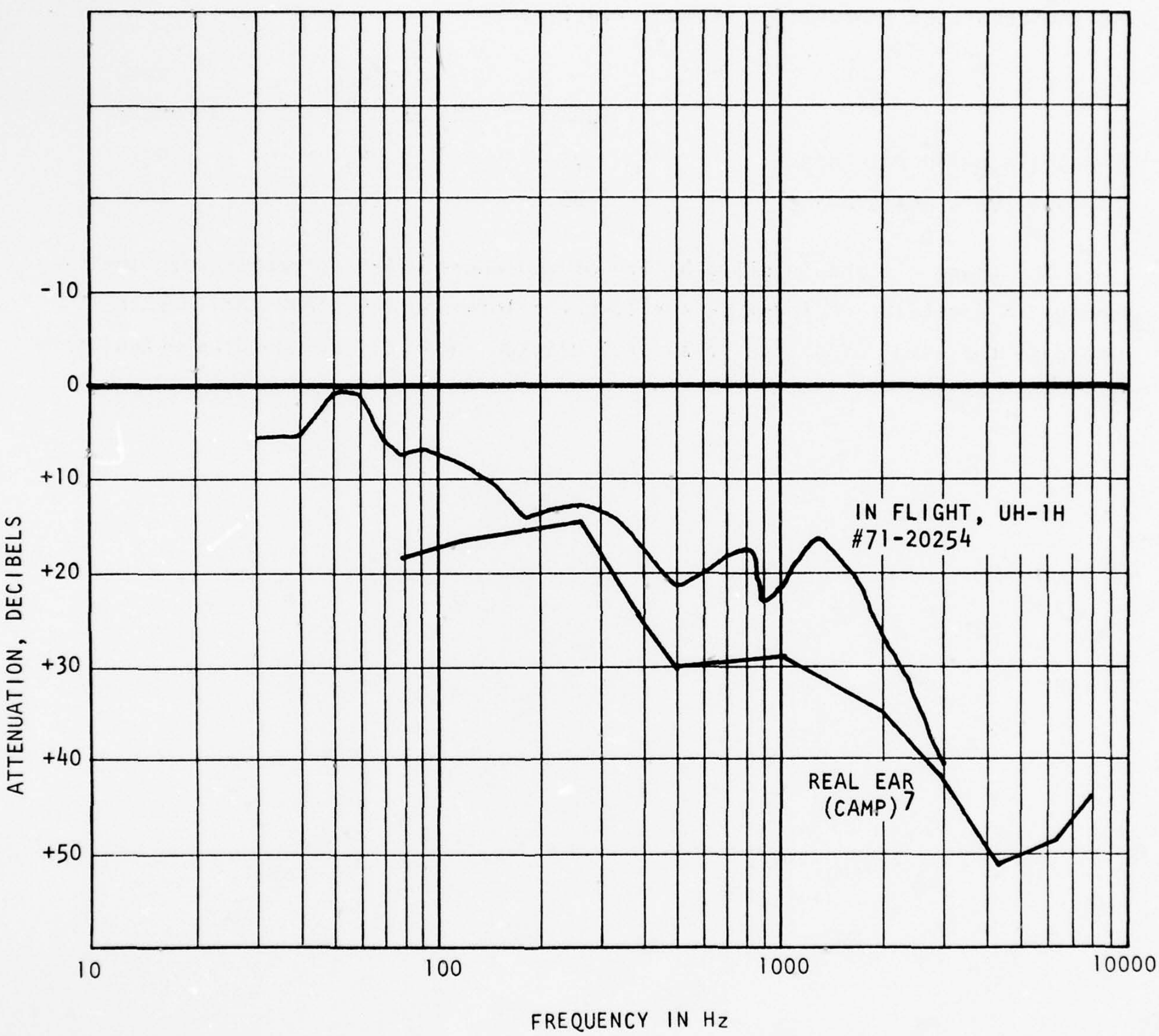


FIGURE 53. EARCUP ATTENUATION EXAMPLE, SPH-4 HELMET

SPH-4 helmet. Tables 9 and 10 show the effect on articulation index of obtaining a result as good as the laboratory measurement. The result in #71-20254 was actually somewhat better than typically obtained in the UH-1H in this study, so the predicted improvement is conservative.

	AI	SENTENCE INTELLIGIBILITY	WORD INTELLIGIBILITY
SPH-4 (in UH-1H #71-20254)	.77	98%	93%
SPH-4 (Camp's measurement)[7]	.86	99	96

The change in the intelligibility of sentences which corresponds to the change in articulation index is small, but pilots would be less inclined to increase the level of speech if an articulation index of .86 could be established at lower levels.

UH-1H NO. 71-20254
LEVEL FLIGHT.

TABLE 9. REGULAR EARCUP

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	59.7	60.0
380.0	54.2	52.9
490.0	55.8	44.3
630.0	57.6	42.1
770.0	53.1	42.3
920.0	50.3	37.1
1070.0	49.0	39.0
1230.0	51.4	38.8
1400.0	51.0	36.7
1570.0	51.5	35.9
1740.0	48.7	34.6
1920.0	47.7	32.6
2130.0	46.9	32.2
2370.0	48.1	32.2
2660.0	57.4	40.0
3000.0	54.8	39.7
3400.0	45.4	36.6
3950.0	37.0	32.9
4560.0	34.0	28.5
5600.0	27.8	22.5

OASL(DBA) = 88.5 77.3

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 88.9 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	60.0	16.5	60.0
380.0	52.9	11.6	52.9
490.0	44.3	7.9	44.3
630.0	42.1	4.3	42.1
770.0	42.3	1.4	42.3
920.0	37.1	0.0	37.1
1070.0	39.0	0.0	39.0
1230.0	38.8	0.0	38.8
1400.0	36.7	0.0	36.7
1570.0	35.9	0.0	35.9
1740.0	34.6	0.0	34.6
1920.0	32.6	0.0	32.6
2130.0	32.2	0.0	32.2
2370.0	32.2	0.0	32.2
2660.0	40.0	0.0	40.0
3000.0	39.7	0.0	39.7
3400.0	36.6	0.0	36.6
3950.0	32.9	0.0	32.9
4560.0	28.5	0.0	28.5
5600.0	22.5	0.0	22.5

ARTICULATION INDEX = .77

TABLE 10. IMPROVED EARCUP

UH-1H 71-20254
LEVEL FLIGHT, IMPROVED EARCUP

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	59.7	58.3
380.0	54.2	46.0
490.0	55.8	35.3
630.0	57.6	32.1
770.0	53.1	30.6
920.0	50.3	31.1
1070.0	49.0	31.4
1230.0	51.4	28.8
1400.0	51.0	22.5
1570.0	51.5	22.5
1740.0	48.7	22.9
1920.0	47.7	23.3
2130.0	46.9	32.2
2370.0	48.1	32.2
2660.0	57.4	40.0
3000.0	54.8	39.7
3400.0	45.4	36.6
3950.0	37.0	32.9
4560.0	34.0	28.5
5600.0	27.8	22.5

OASL(DBA) = 88.5 75.1

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 88.7 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	58.3	16.5	58.3
380.0	46.0	11.6	46.0
490.0	35.3	7.9	35.3
630.0	32.1	4.3	32.1
770.0	30.6	1.4	30.6
920.0	31.1	0.0	31.1
1070.0	31.4	0.0	31.4
1230.0	28.8	0.0	28.8
1400.0	22.5	0.0	22.5
1570.0	22.5	0.0	22.5
1740.0	22.9	0.0	22.9
1920.0	23.3	0.0	23.3
2130.0	32.2	0.0	32.2
2370.0	32.2	0.0	32.2
2660.0	40.0	0.0	40.0
3000.0	39.7	0.0	39.7
3400.0	36.6	0.0	36.6
3950.0	32.9	0.0	32.9
4560.0	28.5	0.0	28.5
5600.0	22.5	0.0	22.5

ARTICULATION INDEX = .86

9.0 HEARING CONSERVATION PROGRAMS IN THE MILITARY SERVICES

9.1 ORGANIZATION

Activities related to hearing conservation in the services are generally under three classifications: environmental health, medical R&D, and clinical services. This organization of effort is common to each of the services, although the responsibilities for specific components of the program are not allocated the same in every case. The cognizant offices for each of the services are listed below:

	ENVIRONMENTAL HEALTH	MEDICAL R&D	CLINICAL SERVICES
ARMY:	Army Environmental Hygiene Agency Edgewood Arsenal, Md.	Army Aeromedical Research Ft. Rucker, Al.	Army Clinical Division Walter Reed Hospital Washington, D. C.
NAVY:	Navy Environmental Health Center Cincinnati, Ohio	Navy Environmental Supply Pt. Hueneme, Ca.	Naval Aerospace Medicine for Industry Pensacola, Florida
AIR FORCE:	Bioacoustics Division Wright-Patterson AFB Ohio	Hq. USAF/SGTA Forrestall Bldg. Washington, D. C.	USAFSAM/NG Clinical Sciences Division Brooks AFB, Tx.

The authority for administration of the hearing conservation program begins with the Clinical Services in both the Army and Navy, but in the Air Force, Medical R&D is responsible for the program. The Air Force has the oldest of the three programs. The Air Force program is covered and supported by very specific regulations. In 1978, a similar U. S. Army program was approved by the Department of Defense. Implementation of the Army program is expected by October 1978.

Despite the differences in program authority mentioned above, the three agencies in which the hearing conservation program resides have similar functions. The Clinical Services provide medical services at the various bases where personnel are working in noise-hazardous environments. Environmental Health agencies are in general concerned with the setting of standards and with the functional

design of the program. Medical R&D is a somewhat misleading title, in that research and development activities are also carried out by the other two agencies, especially the Clinical Services. Medical R&D is more concerned with the development of protective equipment and devices, whereas the Clinical Services engage in evaluations of equipment and conservation practices in the field. Research is involved in both of these functions, but in the Clinical Services the research is conducted primarily by military personnel.

An idea of the magnitude of the overall effort devoted to airborne acoustics by all the armed services can be obtained from the "Directory of DoD Contacts on Airborne Acoustics.[86] At the time this directory was published there were 409 personnel in 80 offices involved in this activity. The breakdown was as follows:

	Offices	Personnel
Army	8	116
Navy	37	112
Air Force	34	160
Marine Corps	1	1

Fewer than 10 percent of the personnel had titles which indicated that their primary duties were concerned with hearing problems associated with aircraft noise. It is likely that the activities in this area have increased significantly since the directory was published, however.

9.2 ADMINISTRATION

The new Army program is covered by Army Regulation 40-5. AR40-5 is being updated as it addresses hearing conservation as well as other health areas. Updates of TB-Med 251, MIL-STD-1474A[101] and MIL-A-8806[29] have been made or are expected. The Army program includes such measures as noise-damage orientation for new recruits, the establishment of noise hazard assessment codes, and annual or semi-annual audiograms for personnel working in areas where levels exceed 85 dBA.

The administration of medical control procedures according to TB-Med 251 can be viewed by means of the flow chart of Figure 54. This chart shows parallel avenues of handling, depending on whether the audiological examination is the entrance examination, designed to establish a baseline hearing threshold against which subsequent tests will be compared, or whether the examination is the routine annual checkup. Usually the personnel have been working in the high noise environment for at least a short time prior to the baseline tests, which is unfortunate. The procedural differences occur in the event that personnel fail both the first test and the subsequent test 24 hours later. In the case of routine annual check, the personnel are given more opportunities to finally pass a test and return to duty. The reasons are obvious: both the Army and the personnel have a considerable career investment (especially for flight personnel) at this point. This loss is considerably larger than the disability compensation. As long as no serious threshold shift (TS) is observed, the procedure will continue to examine the personnel once a year. Furthermore, any passing of an audiological test will return the person to high noise duty, regardless of his performance on a previous test.

It is interesting to compare Figure 54 with Figure 55, which is a flow chart for the Air Force case disposition procedure (from Gasaway and Sullivan[35]). Here we see that each stage of the procedure is covered by a corresponding section of AFR 161-35.[87] Note that personnel who never show evidence of a TS are rechecked only once a year, as in TB-Med 251. The reference (or baseline) audio is followed up in 90 days with an audio, regardless of baseline performance. But the major difference in the USAF procedure is the handling of cases which have shown TS in either the 90-day or annual audio. Aside from differences in testing intervals, the personnel who fail the next two tests are then entered into a rigorous testing routine which (depending on outcome of the detailed follow-up examination) has a duration of five months and six examinations, even in the case that the subject passes all six tests during this "clinical" period. This procedure is designed to make sure that a patient has completely recovered from the TS before he is returned to duty in the high noise environment. TB-Med 251, on the other hand, has no comparable precautionary procedure.

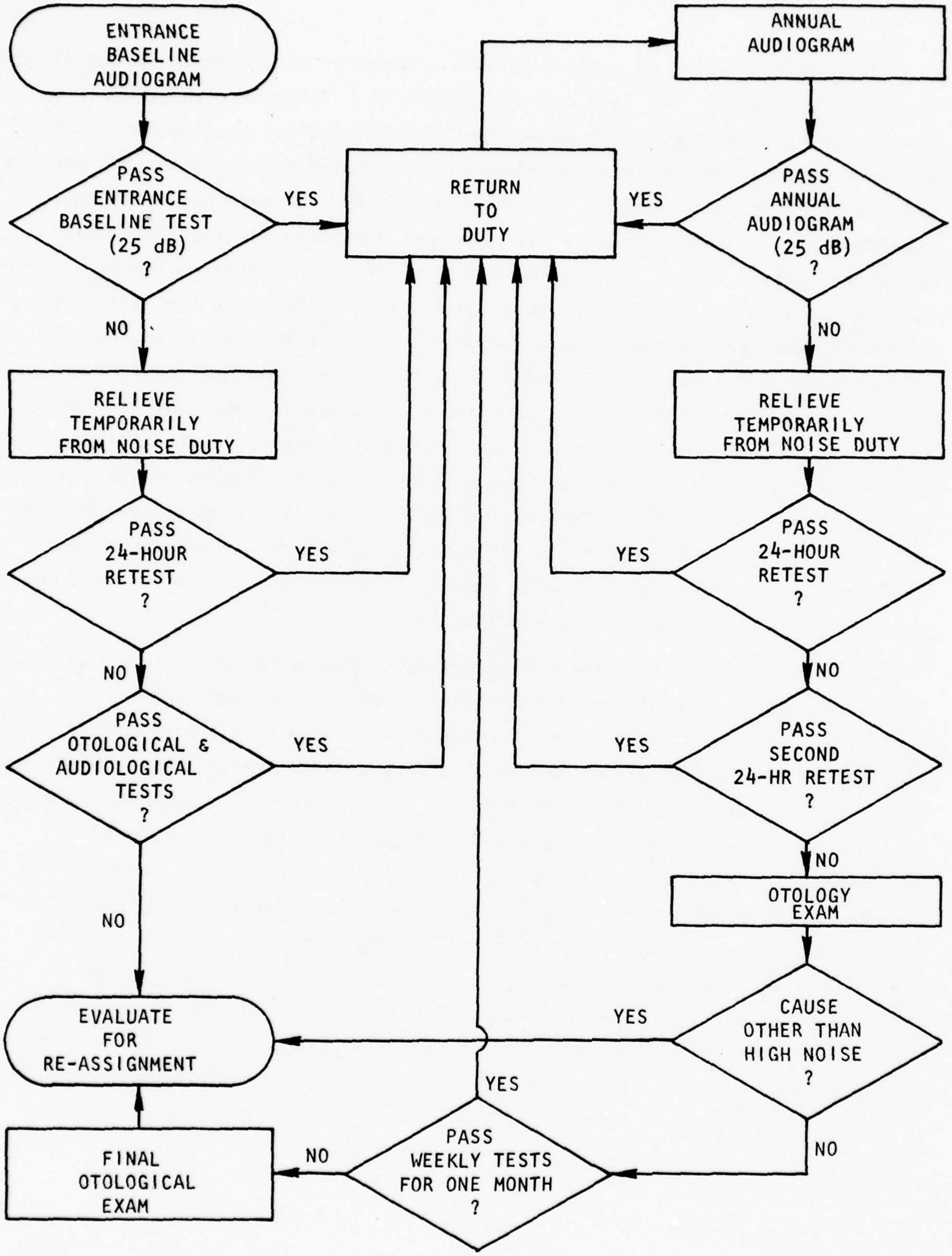
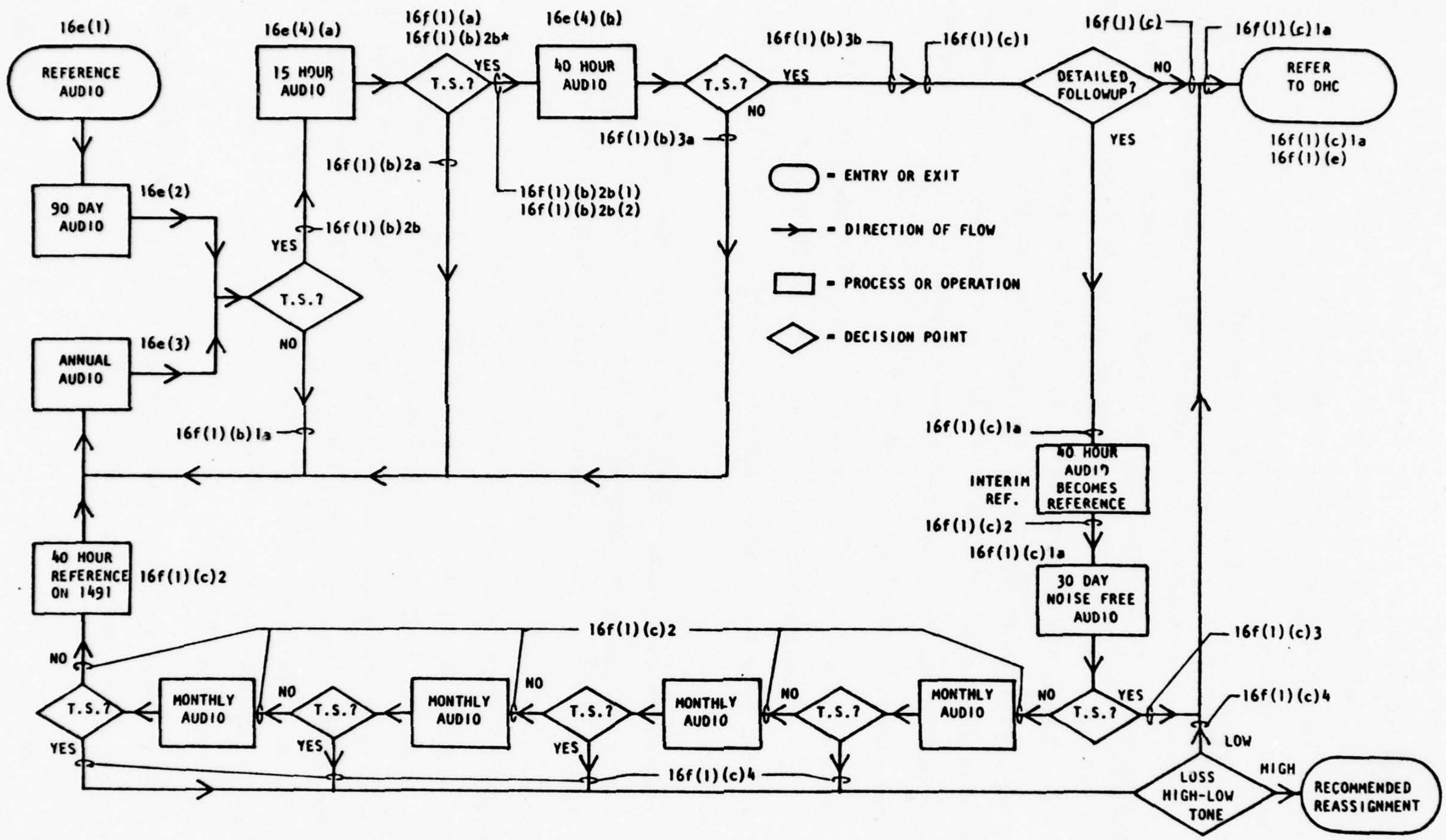


FIGURE 54. CASE DISPOSITIONS RECOMMENDED BY U.S. ARMY TB-MED 251 (HIGH NOISE ENVIRONMENT)



*Dispositions relative to hearing conservation are based on TS, not hearing profile, See 16f(1)(d)

FIGURE 55. CASE DISPOSITIONS DETAILED IN USAF-161-35 (HIGH NOISE ENVIRONMENTS)

The patient may immediately exit the clinical stage only by failing another audio. At this point he will be either referred to Division Health Center (DHC) or recommended for re-assignment, depending on whether the nature of the TS is in low tones or high tones. Very rigorous audio tests must be passed before the subject can be returned to a high noise environment.

The USAF disposition procedures are actually more complex than shown in Figure 55. For example, if a person demonstrated significant TS which persisted on the 15-hour recheck, the procedure is not as shown in Figure 55(See Gasaway and Sullivan[35]). Before the 40-hour audio is given, the person is examined by the attending physician to determine the apparent cause of the TS, and the 40-hour recheck is then entered only after (a) no cause was found, or (b) the cause was found and corrected. The procedure between the 15-hour and 40-hour rechecks is then actually as shown in Figure 56.

The USAF procedures differ in other ways, also. For example, the critical threshold shift for TS determinations is lower, 10-20 dB rather than 25 dB, and they differ also from one classification or stage to another in the classification procedures.

The Navy program is also known to be in a transitional stage. Navy procedures for the disposition of cases are covered by an "instruction", which is similar to a regulation (BUMEDINST[88]). This instruction was issued in 1970 and is now considered obsolete. Navy officials believe that there will be a move to standardize the procedures of the hearing conservation program, and also to consolidate it within no more than three agencies, as opposed to the present nine. In the present configuration, the Navy program (as applied to aviation) is administered by a different program manager for each type of aircraft. The critical TS for Navy personnel working in noise-hazardous environments is 25 dBA at any frequency through 3,000 Hz, so far as special handling is concerned. If permanent TS of 40 dBA is determined for the better ear, the person is reassigned to an environment with noise level not exceeding 90 dBA.

The Air Force program has resulted in better hearing among Air Force flight personnel than among the general public.[35]

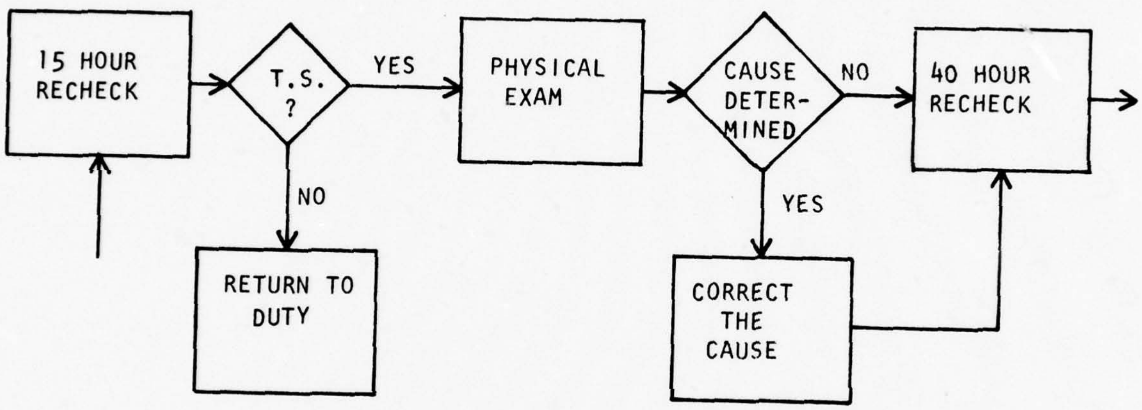


FIGURE 56. STEPS BETWEEN THE 15-HR. AND 40-HR. AUDIO RECHECKS SHOWN ON FIGURE 55.

10.0 CONCLUSIONS AND RECOMMENDATIONS

Before proceeding to the conclusions, some of the assumptions on which those conclusions depend will be stated. These assumptions are as follows:

- The 7 aircraft types in which data were taken are representative of aircraft in the U. S. Army inventory. If other aircraft, or future aircraft, generate noise having a different level or spectrum shape, the conclusions would be altered. For example, flat spectra of the same overall noise power would lead us to emphasize the characteristics of microphones rather than helmets and earcups.
- The comparison method of measuring earcup attenuation used in this project provides a good measure of real-ear attenuation (However, see Section 4.7).
- The SPH-4 helmet and M-87 microphones used during the project are typical.
- The observers who took the data are typical of U. S. Army aviators, with regard to fit and technique when wearing the SPH-4 helmet.

10.1 THE NOISE ENVIRONMENT

The noise spectra which are found in the communications systems of the U. S. Army aircraft can be described by the following model.

- A low-frequency spectrum in the earcup which slopes downward as frequency increases, primarily due to noise leakage into the earcup. In terms of its effect on speech intelligibility and hearing damage, this noise is negligible above about 1000 Hz.
- A high-frequency spectrum in the earcup which slopes upward as frequency increases, due to noise which is picked up at the microphone and transmitted to the earphone. This noise is present only when a microphone is keyed. In terms of its effect on speech intelligibility and hearing damage, this noise is negligible below about 1000 Hz.

There is additional sound in the earcup due to speech which is transmitted on the communication channel. In terms of its effect on hearing damage, the speech level is significant from about 400 Hz up to the upper limit of the microphone/earcup frequency response, which is about 6000 Hz.

The model described here is illustrated by Figures 9 and 12 in Section 4.

For the aircraft studied during this project, between 72% and 89% of the noise power (calculated after A-weighting the noise spectra) is due to earcup leakage.

10.2 INTELLIGIBILITY AND HEARING DAMAGE RISK

Table 3 in Section 5 shows that typical calculated values for the intelligibility of electronically-communicated speech within helicopters are in excess of 95 percent (for sentences). However, operating conditions are marginal for good intelligibility (see Section 5.8). Slight changes in speech levels, speech quality, or background noise sometimes cause large decreases in intelligibility. Temporary lapses of intelligibility may cause pilots to form a habit of routinely turning up volume controls to their maximum settings. The unnatural quality of received speech signals also may cause them to form that habit, although the peculiar quality of the speech, such as the emphasis of plosives, may actually increase its intelligibility for practiced listeners (see Section 3.5).

Currently accepted criteria for predicting hearing losses which result from noise exposure lead one to conclude from Table 3 that those noise levels will cause what is currently accepted to be a hearing handicap (see Section 3.3) in only a small fraction of one percent of all exposed personnel who wear helmets at least as good as SPH-4 helmets. Therefore, based on the analysis of data collected during this project, a prediction of widespread hearing loss, due to service in aircraft, cannot be justified.

Noise sources, sufficiently loud to be damaging to hearing are found in many places, including the leisure-time environment e.g., loud music, motorcycle and motorboats, chain saws, and shotguns. Another possible source is found in non-flying military service. In Section 5.9, evidence is cited that significant hearing loss is sustained in military basic and advanced training.

The observers in this project turned their volume controls to mid-range. If helicopter pilots turn up volume controls only until speech levels which correspond to about 98 percent intelligibility of sentences are reached, then only a few percent of Army helicopter pilots are in danger of suffering a noise-induced permanent threshold shift of more than 10 decibels as a result of being exposed to helicopter noise. However, if they routinely turn up volume controls to maximum settings in attempts to overcome real or imagined problems with intelligibility, then they are in danger of suffering handicapping hearing losses (see section 5.10).

Most existing military aircraft have been developed under contracts which require that internal noise levels comply with MIL-A-8806A.[29] Gasaway[4,89] published measured values of noise levels within cockpits of helicopters. His measurements and the measurements which are presented in this report show that most helicopters are in compliance with MIL-A-8806A.

Table 11 shows the noise levels that are generated at the ears of a crewmember who wears a SPH-4 helmet within a helicopter that generates noise levels equal to the maximum noise levels that are allowed by MIL-A-8806A. That table, and typical in-flight measurements of SPH-4 attenuation, show that such a crew member will be exposed to an overall noise level which is 2 dB higher than is allowed by the Occupational Safety and Health Administration (OSHA) and is 7 dB higher than is allowed by TB Med 251 (see Section 3.3).

10.3 EQUIPMENT PERFORMANCE

The contribution to acoustic noise at the ear due to electrical self-noise in the communications equipment is negligible (Section 6). The distortion, dynamic range, frequency response, and limiting characteristics of the aircraft intercommunication (AIC) sets are generally within specifications (Table 5). Assuming that volume settings are similar to those used during this project, the AIC is not a factor in causing hearing damage or lack of intelligibility. Peaks in the earphone response between 2 kHz and 6 kHz do allow the possibility of hearing damage for high volume settings. To determine whether this actually does occur, more information would be needed about the distribution of volume settings, the percentage of time that speech is received, and the amplitude distribution of speech in this range.

TABLE 11

COMPARISON OF MIL-A-8806A WITH HEARING LOSS CRITERIA

OCTAVE BAND CENTER FREQUENCY	MIL-A-8806 A MAXIMUM ACCEPTABLE NOISE LEVEL FOR MAXIMUM CONTINUOUS POWER (Where helmets are required)		ATTENUATION OF SPH-4 HELMET (From Figure 46)		NOISE LEVELS AT A CREW MEMBER'S EARS	
			TYPICAL IN-FLIGHT	MAXIMUM REAL EAR (CAMP)	TYPICAL IN-FLIGHT	MINIMUM FOR A REAL EAR
(Hertz)	(dB SPL)	(dBA)	(dB)	(dB)	(dBA)	(dBA)
31.5	111	72	8	19	64	53
63	111	85	5	18	80	67
125	111	95	5	17	90	78
250	111	102	9	17	93	85
500	109	106	15	30	91	76
1000	106	106	19	29	87	77
2000	100	101	24	35	77	66
4000	94	95	31	49	64	46
8000	94	93	36	44	57	49
Overall	113	111	14	24	97	87
			For the Particular Noise Profile From MIL-A-8806A		Maximum Allowed For 4 Hour Daily Exposure is 90 dBA For TB Med 251, and 95 dBA for OSHA.	

There was no difference in the in-flight performance of the C-1611D and C-6533 AIC's.

The specification for the M-87 microphone (MIL-M-26542A) requires that the noise-immunity be at least 7 1/2 dB at 1000 Hz. A few recently manufactured or well-cared-for M-87's which have been measured at Advanced Technology Center do meet the specification (see Figure 51). They also meet the response specification. Recently developed microphones (Figure 52) provide several dB improvement in noise-immunity, and are probably close to the maximum noise-cancelling performance which is possible.

Noise-immunity and intelligibility have been measured during this project by employing objective tests. There may be subjective factors which are important to in-flight performance, e.g., reduction of fatigue, reduction of the tendency to turn up volume controls, and intangible contributions to intelligiblity. The performance of improved microphones is ultimately best determined by comparison tests with real voices and real ears.

Earcups remain as the weak link for noise rejection in the communication system. The problem observed in this project is principally one of noise leakage past the earcup seal due to poor fit, insufficient adjustment, the wearing of eyeglasses, long hair, and possibly deterioration of the cushion material.

In cases where an adequate seal is obtained, earcup "pumping" remains as the major cause of noise at the ear. An SPH-4 tested in the laboratory during this project (not the unit used in the aircraft) did not provide as much attenuation near 100 Hz as obtained by other observers (compare Figures 35 and 38 to Figure 46), even when a best seal is made. This is possibly due to manufacturing tolerances or cushion deterioration. The SPH-4 earcup shell itself appears to be adequately rigid.

It is largely low frequency noise (below about 600 Hz) that is responsible for risk of hearing loss and for low intelligibility of speech within helicopters, because that noise is not attenuated appreciably by ear protection devices. There is little hope of reducing the low frequency noise by retrofitting existing aircraft, and new helicopters can be quieted only by introducing considerations of noise control early in the design sequence. Such considerations are expensive and time-consuming, and they increase the cost and subtract from the performance

of helicopters; therefore, it is likely that ear protectors will continue to provide the main means of controlling the impact of low frequency noise on helicopter pilots and crew members. Along with the reduction of low frequency noise to unobtrusive levels, changes in microphones, earphones, and associated electronics can be introduced to improve intelligibility further.

If TB Med 251 is applied to protect occupants of helicopters from hearing loss, then 1 1/2 percent of exposed helmeted personnel will suffer noise-induced threshold shifts between 5 and 10 decibels (in addition to 1/2 percent who will experience that hearing loss even if they are not exposed to loud noise). At the level of protection provided by TB Med 251, no one is expected to suffer an handicapping loss of hearing (barring disease or the action of toxic chemicals). Therefore, TB Med 251 is appropriate for regulation of the exposure of occupants of helicopters to noise.

10.4 RECOMMENDATIONS

Following are recommendations for modifications of U. S. Army practices and equipment, and for future studies.

- The main problem in evaluating the results of the development of new types of microphones, earcups, helmets, and other hardware is that test equipment and methods vary significantly among contractors. It is literally impossible to evaluate the significance of many putative advances because of this problem. When future contracts are let, there should at least be a requirement that a standard test method be used. The equipment should be examined and approved by the contractor's technical representative. The test distance for noise-cancelling microphones is 1/4-inch, so an error of only 1/32 of an inch can make a significant change in the observed performance. A preferred requirement would be that the developed hardware be submitted to an independent testing facility. The test report should then be published as an integral part of the final report. In recent years, the U. S. Army has developed facilities which are capable of meeting this requirement, if the tests are conducted so that objectivity is maintained.

- Although a number of ideas have been proposed for reducing earcup pumping and interference by eyeglasses and hair (see Section 8.2), it is not clear which, if any, of these are practical for operational use. In the absence of entirely new concepts, further developments should be conducted by manufacturer's of helmets and earcups. The manufacturer's are in the best position to make operating prototypes and to evaluate manufacturability and cost. It may be possible to develop helmets which provide adequate protection even when they are not fitted well.

- There is considerable evidence that existing equipment is not used optimally, and that less hearing loss would occur if equipment were used optimally. For example, pilots and crewman probably unnecessarily and routinely turn volume controls to high loudness positions. They should be trained to reduce listening levels, so that hearing is preserved with little or no loss in intelligibility of voice messages. Pilots and crew members also probably do not position and seat earphone earcups optimally. They should be instructed in the optimum use of earcups so that risks of hearing damage will be reduced. If they could be instructed in the use of earplugs, and encouraged to wear them, considerable additional protection against hearing loss could be achieved.

- The method of fitting helmets should be reviewed. Possibly, objective methods of evaluating performance in the fitting room can be developed, by using an instrumented helmet for the first phase of the fitting procedure.

- Noise-immunity and response measurements should be made on a sample of microphones which have been in extended service, to identify problems of deterioration of performance. A similar program is applicable to ear cushions.

- Attempts to modify existing helicopters to reduce noise in the cabin have been constrained by the type and location of structural members and power-train components. A program should be funded to develop a purely research helicopter in which a specified noise level is to be achieved. It would then be required that noise-reducing features be incorporated into the load-carrying and power-train components rather than added on. Such a program could be a source of new concepts for noise reduction.

- A study of the feasibility of limiting volume settings on electronic communication equipment should be conducted. If improved earcups and electronics can be developed, then high speech levels will be unnecessary even under adverse circumstances, and lowered limits on volume settings might be feasible.

- Some attempt should be made to define and document the origins of hearing losses that have been measured among helicopter pilots. Only estimates of those origins are obtainable for past environments. The number of hours of exposure at various noise levels within helicopters must be estimated, and lifetime exposures to loud noise outside the helicopters must be estimated. It is likely that such studies will reveal that hearing losses experienced by many helicopter pilots are due to exposures to damaging noises (such as noise from small-arms fire) which are unrelated to helicopter noise. Data which were presented in Section 5.10 give some support for that thesis. Information which is related to all hearing loss claims that are handled by the Veterans Administration is stored on punched cards at VA headquarters. A computerized analysis of the information which is on those cards could yield numbers for the percentage of hearing loss claims that result in compensation and for distributions of amounts of compensation that are granted. Such numbers would be useful in defining factors other than exposure to helicopter noise which contributed to hearing loss among helicopter crewmen. It would be particularly informative to list distributions of amounts of compensation by VA office and region, since factors that are not related to exposure to helicopter noise might correlate with VA office and region.

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12.0 REFERENCES

1. Walden, B. E., Worthington, D. N., McCurdy, H. W. "The Extent of Hearing Loss in the Army, A Survey Report," U. S. Army Medical Research and Development Command, Walter Reed General Hospital (December 1971) AD 739 931.

2. Gasaway, D. C. (1971). "Noise Within Fixed-Wing Utility Aircraft Used by the Military," SAM-TR-71-43, USAF School of Aerospace Medicine, Brooks AFB, Tx. (AD 742 972).

3. Gasaway, D. C. (1975). "A-Weighted Sound Levels in Cockpits of Fixed - and Rotary Winged Aircraft," SAM-TR-75-22, USAF School of Aerospace Medicine, Brooks AFB, Tx, August.

4. Gasaway, D. C. (1976). "Noise Levels Measured Within Aircraft During Takeoff, Climb, and Cruise (Low, Normal and High)," SAM-TR-76-9, USAF School of Aerospace Medicine, Brooks AFB, Tx.

5. Military Specification MIL-E-25670 (USAF), Earphone H-143/AIC (29 May 1957)

6. Military Specification MIL-M-26542A (USAF), Microphone, Dynamic M-87/AIC (20 December 1962)

7. Giordano, T. A. and Keane, G. C., (1973). "The Effect of Helicopter Noise on Communication and Hearing," (ECOM-4140, U. S. Army ECOM, Ft. Monmouth, New Jersey.

8. Bruce, R. D. (1971). "Field Measurements: Equipment and Techniques," Chapter 4 of Noise and Vibration Control, edited by Leo L. Beranek, McGraw-Hill Book Co., New York.

9. von Gierke, H. E. (1975). "Noise - How Much is Too Much?", Noise Control Engineering, July-August.

10. Guignard, J. C. and Johnson, D. L. (1975). "The Relation of Noise Exposure to Noise Induced Hearing Damage," Sound and Vibration, Jan.

11. EPA (U. S. Environmental Protection Agency) (1974). "Information on Levels of Environmental Noise Requisite to Protect Publication Health and Welfare with an Adequate Margin of Safety," Report No. 550/9-74-004, March.

12. Randall, R. H. (1951). Introduction to Acoustics, Addison-Wesley Press, Inc., Cambridge 42, Mass.

13. OSHA (U. S. Occupational Safety and Health Administration)(1974). "Occupational Noise Exposure, Proposed Requirements and Procedures," Federal Register, 39, No. 207, 37773-37778, October 24.

14. TB Med 251 (1972). "Noise and Conservation of Hearing," Headquarters, Dept. of the Army, 7 March.

15. Kryter, K. D. (1973). "Impairment to Hearing from Exposure to Noise," JASA, 53, No. 5.

16. Glorig, A. (1971). "Damage-risk Criteria for Hearing," Chapter 17 of Noise and Vibration Control, edited by Leo L. Beranek, McGraw-Hill Book Company, New York.

17. VA (U. S. Veteran's Administration)(1975). "VA Proposed Revision to the Schedule for Rating Disabilities," U. S. Government Printing Office, Washington.

18. EPA (U. S. Environmental Protection Agency)(1973). "Prediction of NIPTS due to Continuous Noise Exposure," Report No. EPA 550/9-73-001-B.

19. ANSI S3-5 (1969), ANSI Standard S3.5, "Methods for Calculation of the Articulation Index," American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

20. Niederjohn, R. J. and Grotelueschen, J. H. (1976). "The Enhancement of Speech Intelligibility in High Noise Levels by High-Pass Filtering Followed by Rapid Amplitude Compression," IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. ASSP-24, No. 4, August.

21. Camp, Jr., R. T., (1968). "Philosophies of Voice Communication Systems Design," AGARD Conference, London, October.

22. Gasaway, D. C. (1970). "Six Indices for Predicting Speech Interference within Aircraft," USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas, Report No. SAM-TR-70-72, December.

23. Pickett, J. M. and Pollack, I. (1958). "Prediction of Speech Intelligibility at High Noise Levels," JASA, 30.

24. Gasaway, D. C. (1974). "Acoustic Alteration of Speech Processed through Air Force Aircraft Communications Systems," USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas, Report No. SAM-TR-74-37, November.

25. TREC (1961). "Study to Establish Realistic Acoustic Design Criteria for future Army Aircraft," U. S. Army Transportation Research Command, Fort Eustis, Virginia, TREC Tech. Rpt. 61-72.

26. Cox, C. R. (1970). "Design Considerations for Acceptable Cabin Noise Levels in Light Helicopters," American Helicopter Society Symposium on Environmental Effects on VTOL Designs, Arlington, Texas, November, Preprint No. SW-70-23.

27. Weinreb, L. and Touger, M. L. (1960). "Variation in Ear Protector Attenuation as Measured by Different Methods," JASA 32, 245-249.

28. Duncan, Acheson J. (1965). Quality Control and Industrial Statistics, Third Edition, Richard D. Irwin, Inc., Homewood, Illinois.

29. MIL-A-8806 (A) (1967). "Military Specification, Acoustical Noise Levels in Aircraft, General Specifications for", Amendment 1 (12 September).

30. Hamernik, Roger P.; Henderson, Donald; Crossley, James J.; and Salvi, Richard J. (1974). "Interaction of Continuous and Impulsive Noise: Audiometric and Histological Effects", J. Acoustical Soc. Am., 55, No. 1, January.

31. Henderson, Donald and Hamernik, Roger P. (1975). "Contribution of Animal Research to Noise Exposure Criteria," Sound and Vibration, September.

32. Camp, R. T., Mozo, B. T. and Patterson, J. H. (1975). "An Investigation of Aircraft Voice Communications Systems as Sources of Insidious Long-Term Acoustic Hazards," AGARD Conference Proceedings No. 171, paper C12, November, 1975.

33. Walden, Brian E.; Worthington, Don W.; and McCurdy, Harry W. (1971). "The Extent of Hearing Loss in the Army--A Survey Report," U. S. Army Medical Research and Development Command, Washington, D. C., 20314, 21 December (AD 739 931).

34. Stork, R. L. and Gasaway, D. C. (1976). "Evaluation of V-51R and EAR[tm] Earplugs for Use in Flight," USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas, Report No. SAM-TR-77-1, February.

35. Sutherland, H. C. and Gasaway, D. C. (1976). "Hearing Levels of Noise - Exposed U. S. Air Force Personnel Compared to those in the Total U. S. Population," USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas, Report No. SAM-TR-76-27, September.

36. Zwislocki, Josef (1955). "Factors Determining the Sound Attenuation Produced by Earphone Sockets", JASA, 27, No. 1, 146 (jan).

37. Zwislocki, Josef (1957). "Ear Protectors," Chapter 8 of Handbook of Noise Control, Edited by Cyril M. Harris, McGraw-Hill Book Co., Inc., New York.

38. Shaw, E. A. G. and Thiessen, G. J., "Improved Cushion for Ear Defenders," Journal Acoust. Soc. American (January 1958), p. 24-36.

39. Shaw, E. A. G. and Thiessen, G. J., "Acoustics of Circumaural Earphones," JASA, 34, No. 9, (September 1962).

40. Botsford, J. H., "Ear Protectors - Their Characteristics and Uses," Sound and Vibration, November, 1972, p. 24-29.

41. Forstall, J. R., "The Sound Attenuations of Flight Helmets," Sound and Vibration, October 1970, p. 12-17.

42. MIL-A-8870 (ASG) (1960). "Military Specification: Airplane Strength and Rigidity, Vibration, Flutter and Divergence," May 18.

43. Zwislocki, Josef, (1955(b)). "Development of a Semiplastic Earphone Socket," JASA, 27, No. 1, 155 (January).

44. Franke, Ernst K. (1952). "The Impedance of the Human Mastoid," JASA, 24, No. 4, 410.

45. von Gierke, H. E. (1957 a). "Aircraft Noise Sources," Chapter 33 of Handbook of Noise Control, edited by Cyril M. Harris, McGraw-Hill Book Company, Inc., New York.

46. von Gierke, H. E. (1957 b). "Aircraft Noise Control," ibid, chapter 34.

47. Ramakaishnan, R. and Randall, D. and Hosier, R. N. (1975). "A Computer Program to Predict Rotor Rotational Noise of a Stationary Rotor from Blad Loading Coefficient," NASA-TM-X-3281.

48. Sofrin, T. G. (1972). "Fan Noise Mechanisms and Control," Inter-Noise 72 Proceedings, Washington, D. C., October 4-6.

49. Lawson, M. V. (1972). "Fan Noise Mechanisms and Control," Inter-Noise 72 Proceedings, Washington, D. C., October 4-6.

50. Burdsall, E. A. (1972). "Recent Studies of Fan Noise Generation and Reduction," Inter-Noise 72 Proceedings, Washington, D. C. October 4-6.

51. AIAA (1975 a). Aeroacoustics: Jet and Combustion Noise; Duct Acoustics, edited by Henry T. Nagamatsu, Volume 37 of the Progress in Astronautics and Aeronautics Series, MIT Press (By AIAA), Cambridge, Massachusetts.

52. AIAA (1975 b). Aeroacoustics: Fan, STOL, and Boundary Layer Noise; Sonic Boom; Aeroacoustics Instrumentation, edited by Henry T. Nagamatsu, MIT Press (by AIAA), Cambridge, Massachusetts.

53. Jones, W. L. and Heidelberg, L. J. and Goldman, R. G. (1973). "Highly Noise Suppressed Bypass 6 Engine for STOL Application," AIAA paper 73-1031.

54. Henderson, H. R. and Pegg, R. J. and Hilton, D. A. (1973). "Results of the Noise Measurement Program on a Standard and Modified OH-6A Helicopter," NASA TN D-7216, September.

55. Faulkner, H. B. (1974). "The Cost of Noise Reduction in Intercity Commercial Helicopters," J. Aircraft, 11, No. 2, February.

56. Moeller, K. G. F. (1957). "Gear Noise," Chapter 23 of Handbook of Noise Control, edited by Cyril M. Harris, McGraw-Hill Book Company, Inc., New York.

57. Badgley, R. H. and Chiang, T. (1972). "Investigation of Gearbox Design Modifications for Reducing Helicopter Gearbox Noise," AD-742735 (Defense Documentation Center.

58. Gu, A. L. and Badgley, R. H. (1974). "Prediction of Gear-Mesh-Induced High-Frequency Vibration Spectra in Geared Power Trains," AD-777496 (Defense Documentation Center).

59. Muster, D. and Plunkett, R. (1971). "Isolation of Vibrations," Chapter 13 of Noise and Vibration Control, edited by Leo L. Beranek, McGraw-Hill Book Company, Inc., New York.

60. Ungar, E. E. and Dietrich, C. W. (1966). "High Frequency Vibration Isolation," J. Sound Vib., 4 (2).

61. Schultz, T. J. (1971). "Wrappings, Enclosures, and Duct Linings," Chapter 15 of Noise and Vibration Control, edited by L. L. Beranek, McGraw-Hill Book Company, New York.

62. Franken, P. A. and Beranek, L. L. (1960). "Noise Control in Transportation," Chapter 25 of Noise Reduction, edited by Leo L. Beranek, McGraw-Hill Book Company, Inc., New York.

63. Seshadri, T. V. (1975). "Shock and Vibration Analysis Using Finite Element Techniques," Shock and Vibration Digest, 7, No. 7, July.

64. Davis, R. F. and Hines, D. E. (1974). "Performance of Statistical Energy Analysis," Shock and Vibration Bulletin, 44, Part 2, August.

65. Mead, D. J. (1973). "A General Theory of Harmonic Wave Propagation in Linear Periodic Systems with Multiple Coupling," J. Sound Vib., 27 (2).

66. Catherines, J. J. and Mayes, W. H. (1975). "Interior Noise Levels of Two Propeller-Driven Light Aircraft," Proceedings of the Technical Program: NOISEXPO, National Noise and Vibration Control Conference, Atlanta, Georgia, April 30-May 2.

67. U. S. Air Force (1965). Acoustical Fatigue in Aircraft Structures, edited by W. J. Trapp and D. M. Forney, Jr., Syracuse University Press, Syracuse, New York.

68. Cremer, L. and Heckl, M. and Ungar, E. E. (1973). Structure-Borne Sound, Springer-Verlag, New York.

69. Ver, I. L. and Holmer, C. I. (1971). "Interaction of Sound Waves with Solid Structures," Chapter II of Noise and Vibration Control, edited by Leo L. Beranek, McGraw-Hill Book Company, Inc., New York.

70. Jones, D. I. G. (1972). "Damping Treatments for Noise and Vibration Control," Sound and Vibration, July.

71. Arctander, Chris (1971). "Sound Absorptive Materials for Aircraft Noise Control," Sound and Vibration, August.

72. Sen Gupta, G. (1975). "Current Developments in Interior Noise and Sonic Fatigue Research," Shock and Vibration Digest, 7, No. 10, Oct.

73. Bowes, Michael A. (1973). "Test and Evaluation of a Quiet Helicopter Configuration HA-43B", JASA, 54, No. 5.

74. Bowes, Michael A. (1977). "Helicopter Noise Reduction Design Trade-Off Study", DOT/FAA Report No. R-1493, January.

75. MIL-H-55351(EL), "Headset Microphone Kit MK 1564( )/AIC(Components of)" 27 May 1971.

76. Edwards, R. G., Hauser, W. P., Moiseev, N. A., Broderson, A. B., and Green, W. W. (1978). "Effectiveness of Earnings as Worn in the Workplace," Sound and Vibration, January, p. 12-22.

77. Rosenheck, et al, "Transducer and Intercommunication System for Air Crewman's Protective Headgear-Final Report," September, 1965, AD 628-980 USAECOM Contract No. DA 28-043AMC-00282(E).

78. Bauer, B. B. and DiMattia, A. L. (1972). "Improved Earphone Enclosure for Communication in Noise," JASA, 51, No. 5, pp. 1388-1393.

79. Meeker, W. F. (1958). "Active Ear Defender Systems: Component Considerations and Theory," Air Force Contract No. AF 33(616)-3051, WADC Technical Report No. 57-368 (September) AD 130 806

80. DiMattia, A. L. and Love, G. V., "Ambient Noise Attenuation," Final Report, USAECOM Contract DAAB07-72-C-0018.

81. Malme, C. I., Allen, C. H. and Schmidt, E. C. H (1973). "Noise Reducing Headset Development," USAECOM Contract No. DAAB07-72-C-0065, Report No. ECOM-0065-F (July).

82. USAECOM Contract DAAB07-71Q-0391 (CBS Laboratories).

83. "System for Operations in High-Ambient Noise," Third-Quarter Report, USAECOM Contract DA 28-043 AMC-00257(E) April (AD 469 080).

84. Rosenheck, A. J., Abbagnaro, L. A., Finger, R. A., DiMattia, A. L., and Bauer, B. B. (1969). "Development of Audio Transducer Helmet Assembly, Final Report USAECOM Contract No. DAAB07-67-C-0204.

85. Brouns, A. J. (1976). "Linear Noise-Cancelling Microphone," ECOM-75-0140-F, USAECOM Contract DAAB07-75-C-0140 June (AD-A025 903).

86. NESCO (1975). "Directory of DOD Contacts on Airborne Acoustics," Report No. 20.2-001, Supplement A, Naval Environmental Protection Support Service, Port Hueneme, CA93043, August, 50 pp.

87. Gasaway, D. C., and Sullivan, H. C. (1977). "Disposition for Personnel Working in High-Noise Environment," USAF Handout (with reference to AFR 161-35).

88. BUMEDINST (1970). 6260.6B, 73-NER-B1, 5 March.

89. Gasaway, Donald C. (1969). "Noise Encountered in Rotary Wing Aircraft", USAF School of Aerospace Medicine, Brooks AFB, Tx, SAM-TR-69-87 (December).

90. Fletcher, John L. (1972). "Conventional and High Frequency Hearing of Naval Crewmen as a Function of Noise Exposure", Memphis State U. Dept. of Psychology, Report No. AD-739368, April.

91. Mayer, M. S., "Acoustic Noise Suppresion in Airborne Communications," ECOM-4336, July 1975, U. S. Army ECOM, Ft. Monmouth, N. J.

92. Goermann, R. R., et al (1960). Aerospace Med., 31, 443.

93. MIL-S-58095 (AV) (1971). "Military Specification, Seat System: Crashworthy, Non-Ejection Aircrew, General Specification for" (27 August).

94. AVSCOM (1976). "AL-1040 Armored Seat Net Deflections", Report No. 75-47 (31 October).

95. von Gierke, Henning E. (1971). "Biodynamic Models and Their Applications", J. Acoustical Soc. Am., 50, No. 6, 1398.

96. ASCC (1975). Air STD 61/1, "Air Standardization Agreement: Ejection Acceleration Limits", 5 September 1975.

97. Slater, John C. and Frank, Nathaniel H. (1947). "Coupled Systems and Normal Coordinates", Chapter VII of Mechanics, McGraw-Hill Book Co., Inc., New York.

98. Lindsay, Robert Bruce (1960). Mechanical Radiation, McGraw-Hill Book Company, Inc., New York.

99. Corliss, Edith L. and Koidan, Walter (1955). "Mechanical Impedance of the Forehead and Mastoid", JASA, 27, No. 6, 1164.

100. Sokolnikoff, I. S. and Redheffer, R. M. (1958). Mathematics of Physics and Modern Engineering, McGraw-Hill Book Co. Inc., New York, Chapter 3, "Functions of Several Variables."

101. MIL-STD-1474A(MI), "Noise Limits for Army Material", 3 March 1975.

BIBLIOGRAPHY

Finkelman, J. M. (1975). "Effects of Noise on Human Performance," Sound and Vibration (September).

Kryter, K. D. (1970). The Effects of Noise on Man, Academic Press, New York.

Griffin, M. J., "The Evaluation of Human Exposure to Helicopter Vibration," Aeronautical Journal, March, 1977, p. 110-123.

Johnson, Daniel L. and Schori, Thomas R. (1977). "How Safe is 115 dBA for 15 Minutes?", J. Acoustical Soc. Am., 61, Supplement No. 1 (abstract), presented at the 93 National Meeting of the Acoustical Society of America.

Rosenheck, A. J., Dimattia, A. L., Allen, R. G., and Torick, E. L., "Transducer and Interphone System for Operation in High Ambient Noise", Final Report, USAECOM Contract No. DA 28-043 AMC-00257((E) (15 July 1966).

APPENDIX A

AIRCRAFT SPECIFICATIONS

The specifications shown in Table A-1 are found in Jane's All The World's Aircraft, 1970-1971 and 1976-1977.

TABLE A-1 AIRCRAFT SPECIFICATIONS

Model	UH-1H	OV-1D	OH-58A	AH-1S(-1Q)	CH-47C	CH-54B
Name	Iroquois	Mohawk	Kiowa	Hueycobra	Chinook	Tarhe
Company	Bell	Grumman	Bell	Bell	Boeing Vertol	Sikorsky
Maximum Weight (kg)	4,309	8,700 Estimated	1,360	4,309	18,000 Estimated	21,000
Engine	One 1044 kW Turboshaft	Two 865 kW Turboprop	One 236 kW Turboshaft	One 1360 kW* Turboshaft	Two 2795 kW Turboshaft	Two 3600 kW Turboshaft
Propeller or Rotor	One 2-bladed Rotor 14.6m Diameter	Two 4-bladed Propellers	One 2-bladed Rotor, 10.8m Diameter	One 2-bladed Rotor, 13.4m Diameter	Two 3-bladed Rotors, 18.3m Diameter	One 6-bladed Rotor, 22.0m Diameter
Propeller, Rotor rpm	294-324	--	354	294-324	240 Approx.	--
Cruise Speed (km/h)	204	480 Estimated	188	352 Maximum Speed	220 Approx.	175

*One 1044 kW turboshaft for AH-1Q

APPENDIX B

DATA ACQUISITION AND FORMAT

APPENDIX B. DATA ACQUISITION AND FORMAT

The acoustical data were collected at two points in the aircraft system. A Bruel & Kjaer (B&K) Model 4133 capacitor microphone, which has a flat response within 1 dB from 10 Hz to 10 kHz, was used to record ambient noise in the cabin or cockpit on one channel of a Nagra Model IV-SJ tape recorder. A Thermo Electron Corporation Model 5333-C electret microphone was used to record earcup noise on the other channel of the Nagra recorder.

The 5333-C was placed in the concha of the crewman's ear, near the opening of the ear canal, and fixed with a non-toxic adhesive. The microphone leads were brought out through a small hole in the SPH-4 earcup. The hole was then sealed. The frequency response of the 5333-C is flat within 1 dB from 10 Hz to 6 kHz.[91] It rises about 3 dB to 10 kHz.

At the beginning of each tape, 250 Hz calibration tones from each microphone were recorded. The calibration source was a B&K Type 4220 pistonphone producing 124 dB SPL. Communication system noise signals were then recorded for various flight and communication conditions. The attenuation settings in each channel were changed as necessary to maximize signal-to-noise and noted in a test log.

In most cases, noise was recorded in the following locations.

	AMBIENT (CAPACITOR MICROPHONE)	EARCUP	APPROXIMATE DISTANCE FROM EARCUP TO CAPACITOR MIC
UH-1H	Center of cabin, 8 to 12-inches below overhead	Cabin	4-6 ft.
OH-58A	Hung from center-top of windshield	Cabin	2-3 ft.
OV-1D	Hung just under standby compass over instrument panel	Co-Pilot	1 ft.
AH-1S, -1Q	Hung from overhead, between seats, left of center	Front Crew	1 ft.
CH-47C	Hung from overhead, in passage just aft of pedestal.	Cabin	1 ft.
CH-54B	Over crew chief's seat	Crew Chief Seat	1 ft.

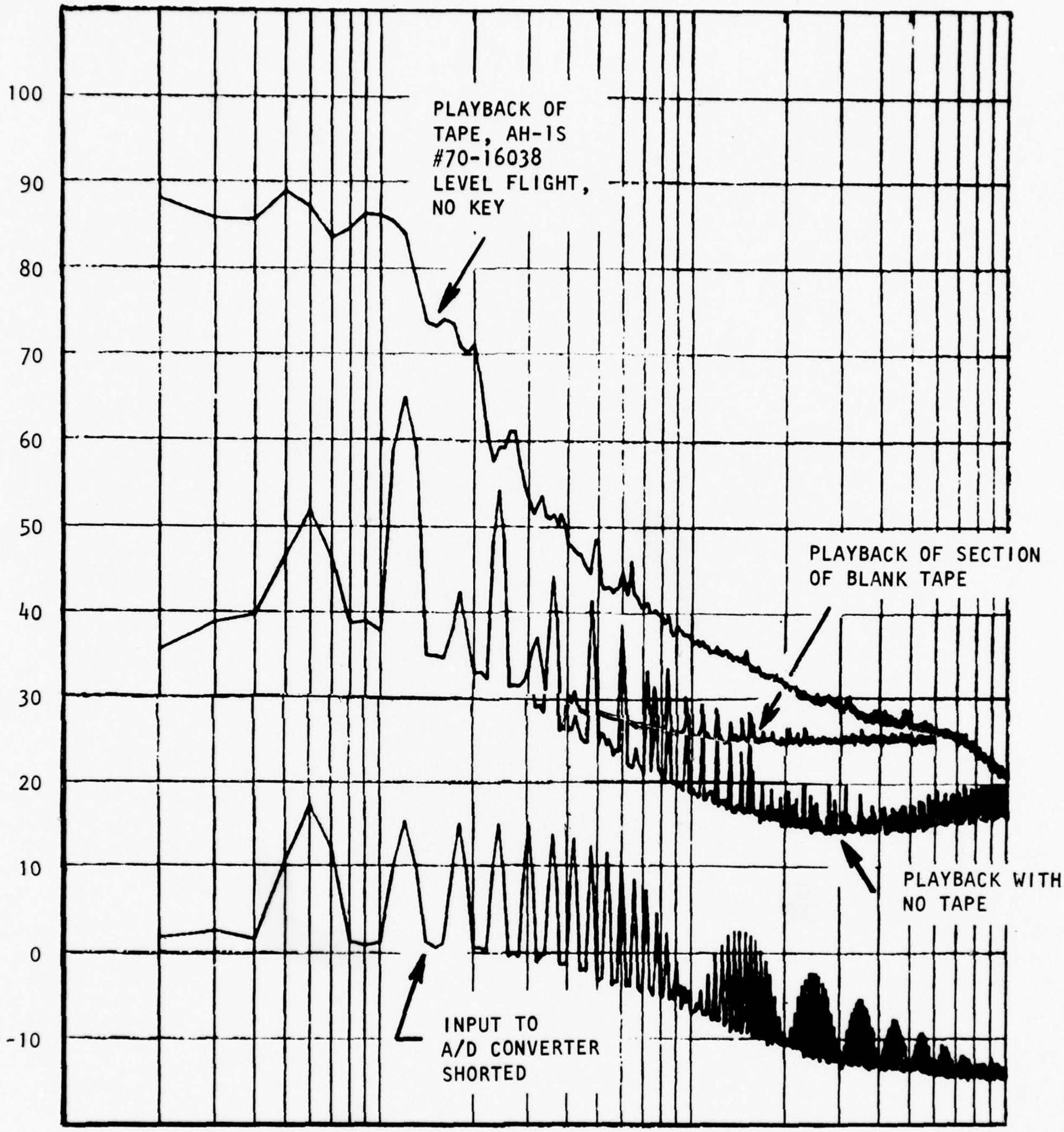
In a separate recording system, the output of a sound level meter was analyzed in the aircraft during level flight operations. The analyzer was a B&K Type 1621 tunable band pass filter. Both 1/3-octave and 3% bandwidth chart recordings were made on a B&K Type 2306 level recorder and included in the log. Level flight ambient noise was also measured on the sound level meter in dBA, and logged.

As the data-taking proceeded, the question arose whether the objective calculations of articulation index would be valid because of the possibility that the AGC action of the microphone preamplifier would cause a gain change when moving from the "no talk" to "talk" condition. Consequently, for some recordings a 1000 Hz tone was inserted in the microphone circuit. Any change in level could then be detected at the earcup, indicating a change in amplifier gain.

The tape recordings of aircraft noise were processed by first digitizing the data, and then performing a Fast Fourier Transform (FFT) analysis as described in Section 3.2. Some additional analysis was done to describe the noise introduced by the tape recorder and the FFT analyzer. Figure B-1 shows the spectrum level (top curve) of NO KEY noise for level flight for one of the AH-1S aircraft. The NO KEY noise at 1000 Hz in the AH-1S is about as low as that in any aircraft. Also shown in Figure B-1 are the equivalent sound pressure of the spectrum noise on a blank section of the same tape, and the noise with no tape passing over the tape head. Finally, the noise introduced by the analog-to-digial (A/D) converter and FFT analyzer is shown.

The noise from the section of blank tape is calculated to have an equivalent A-weighted level of about 68 dBA. The peaks in the spectrum, due to power frequency harmonics, are narrowband and make little contribution to the dBA level. The noise from the tape is thus 14 dB less than the lowest dBA level listed in Table 1. Therefore the dBA levels listed in this report do not include a significant error due to tape noise.

However, at the higher frequencies, the curves of earcup attenuation vs. frequency probably include errors due to tape noise, because the "signal-to-noise" ratio reaches unity at about 5000 Hz. There are also likely to be variations in the noise levels of individual tapes.



100
90
80
70
60
50
40
30
20
10
0
-10
PLAYBACK OF
TAPE, AH-1S
#70-16038
LEVEL FLIGHT,
NO KEY
PLAYBACK OF SECTION
OF BLANK TAPE
PLAYBACK WITH
NO TAPE
INPUT TO
A/D CONVERTER
SHORTED

FIGURE B-1

APPENDIX C

COMMUNICATION SYSTEM NOISE IN 37 AIRCRAFT

APPENDIX C. COMMUNICATION SYSTEM NOISE IN 37 AIRCRAFT

The 37 Tables in this appendix show the A-weighted noise at several points in the communication systems of 37 U.S. Army aircraft, for up to 12 flight modes. A key to the column headings is as follows:

- COCKPIT SLM "SLOW": A reading of A-weighted ambient noise in the cockpit or cabin, taken by USAECOM personnel on a sound-level-meter set to "SLOW" meter-damping.
- COCKPIT AMBIENT CHAN 2: A-weighted ambient noise in the cockpit or cabin; measured off track 2 of the magnetic tape record. The ambient noise from the tape record and the sound level meter log should ideally be the same. For comparisons, see Section 4.0.
- EARCUP NO KEY: The noise at the ear due to leakage through or around the earcup including possible effects of earcup or head vibration, plus the noise output of the earphone due to electrical noise in the headset amplifier. "KEY" refers to actuation of the transmit switch which closes a relay between the microphone circuit or radio receiver and the headset amplifier. The noise from the headset amplifier was actually found to be negligible.
- EARCUP KEY NO TALK: The noise at the ear including the noise described in the previous paragraph, plus noise picked up by the microphone, electrical noise in the microphone amplifier or radio circuits, and noise from electromagnetic interference (EMI). In this study it was found that electrical and EMI noise are negligible and that the only two significant noise paths are leakage through or around the headset including the effects of earcup vibration, and noise picked up and transmitted by the microphone.
- EARCUP KEY TALK: The noise described in the previous paragraph, plus a speech signal ("rainbow passage", see Section 2.0) picked up by the M-87 noise-cancelling microphone, amplified, and delivered to the headset in the SPH-4 helmet. About one-half of the talk entries represent intra-aircraft speech between crew positions (no radio link).

- EARCUP KEY TALK: (CONTINUED)

The other half represent inter-aircraft radio transmissions. There was no significant difference in noise or speech levels between intra- and inter-aircraft communications.

- A.I.: Articulation Index. See Section 3.4.

- SENTENCE INTELL: Sentence intelligibility obtained by entering Figure 7 with the A.I.

- EARCUP ATTEN: Earcup attenuation obtained by subtracting EARCUP NO KEY entries from COCKPIT AMBIENT entries.

- NOISE CROSSOVER: A frequency (usually identifiable by examining spectrum level plots of EARCUP NO KEY and EARCUP KEY NO TALK) below which the noise is predominantly due to earcup leakage and above which the noise is predominantly due to pick-up at the microphone.

Following the tables in this appendix, there are representative computer plots of spectrum level for several aircraft. The resolution of the FFT analysis is 10 Hz. In some plots there is a rising spectrum level in the region above 4 or 5 kHz. This is due to tape hiss or to noise introduced during the analysis. The effective word length for the computer analysis was 13 bits, permitting a dynamic range of approximately 80 dB.

The computer-generated spectra agreed with those obtained in the aircraft by USAECOM personnel, except for small differences due to filter resolution.

All of the OH-58A and OV-1D aircraft used Model C-6533 (SLAE) AIC's. The UH-1H aircraft used C-6533 and C-1611D (PRE-SLAE) AIC's; Tables C-1 through C-10 indicate which AIC in the NOTES. The AH-1S, AH-1Q, CH-47C, and CH-54B aircraft used the C-1611/AIC.

TABLE C-1

AIRCRAFT UH-1H SERIAL NO. 66-16054 FLIGHT DATES 18 Dec 76 CALIB: 250~ Chan 2 Only 1000~ No

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		93							
3 DESCEND RIGHT		96							
4 CLIMB LEFT		93†							
5 DESCEND LEFT		97†							
6 CLIMB RIGHT		94							
7 DESCEND		96							
8 LEVEL FLIGHT	90	95							
9 HOVER AT ALTITUDE		92							
10 HOVER/GND EFFECT		94							
11 LAND									
12 NAP OF EARTH		96 Doors Open							

NOTES: Pilot and copilot windows open on all flights. † One data sample only

C-1611D/AIC

TABLE C-2

AIRCRAFT UH-1H SERIAL NO. 66-16566 FLIGHT DATES 9 Dec 76 CALIB: 250~ Yes 1000~ Not Usable

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		93/93*†	81	84/85*	90	.76	99	12	1500
3 DESCEND RIGHT		90*†			90*				
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		94*	83*	86	90	.71	99	11	1600
8 LEVEL FLIGHT	94	93	83	86	91	.69	99	20	2600
9 HOVER AT ALTITUDE		90	79	83				11	
10 HOVER/GND EFFECT		93	80	83				13	
11 LAND									
12 NAP OF EARTH		94† AIR VENTS OPEN			86 AIR VENTS OPEN				

NOTES: * MAX. PERFORMANCE MANEUVER † ONE DATA SAMPLE ONLY

C-1611D/AIC

TABLE C-3

AIRCRAFT UH-1H SERIAL NO. 68-16612 FLIGHT DATES 23 SEP 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		95	82	83	85	.48	97	13	1600
3 DESCEND RIGHT		98	83	84	86	.23	61	15	500
4 CLIMB LEFT		95	80	83	85			15	750
5 DESCEND LEFT		98	82	85	85			16	
6 CLIMB RIGHT		95	81	82	85	.45	96	14	
7 DESCEND		98	82	84	86	.46	96	16	1200
8 LEVEL FLIGHT	94	96	80	85	86	.34	86	16	1200
9 HOVER AT ALTITUDE		92†	76					16	
10 HOVER/GND EFFECT		91†	77					14	
11 LAND		91†	76					15	
12 NAP OF EARTH									

NOTES: SOUND ABSORPTIVE MAT'L REMOVED ON OVERHEAD AND WALLS. † ONE DATA SAMPLE ONLY.

C-1611D/AIC

TABLE C-4

AIRCRAFT UH-1H SERIAL NO. 68-16622 FLIGHT DATES 3, 8 Nov 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		92	82	82				10	
3 DESCEND RIGHT		96†							
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT		93†			90				
7 DESCEND		95	85	86	89	.68	99	10	
8 LEVEL FLIGHT		93	83	84	90	.71	99	10	
9 HOVER AT ALTITUDE		91	78	80	89	.78	99	13	
10 HOVER/GND EFFECT		91	77	80	90	.74	99	14	
11 LAND									
12 NAP OF EARTH									

NOTES: † ONE DATA SAMPLE ONLY

C-1611D/AIC

TABLE C-5

AIRCRAFT UH-IH SERIAL NO. 68-16628 FLIGHT DATES 2 Dec 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		93	90	84	95	.82	99	3	
3 DESCEND RIGHT									
4 CLIMB LEFT		95†	88					7	
5 DESCEND LEFT		97†	91					6	
6 CLIMB RIGHT		92†		86		.88	99		
7 DESCEND		96	93	87	97	.78	99	3	1400
8 LEVEL FLIGHT	94	94	90	86	96	.86	99	4	
9 HOVER AT ALTITUDE		91	86	83	96	.92	99	5	
10 HOVER/GND EFFECT		93	89	86	96	.82	99	4	1700
11 LAND									
12 NAP OF EARTH									

NOTES: RADIO TO BASE: LEVEL RISES TO 98-99 dBA, PEAKS to 105dBA for 5 SEC. † ONE DATA SAMPLE ONLY

C-1611D/AIC

TABLE C-6

AIRCRAFT UH-1H SERIAL NO. 69-15008 FLIGHT DATES 4 Nov 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		93	86**	90	93	.64	99	7**	2500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		97	92**	92				5**	
8 LEVEL FLIGHT		89	87**	90	93			2**	
9 HOVER AT ALTITUDE		90	85**	87	98	.61	99	5**	
10 HOVER/GND EFFECT		96	84	88				12	
11 LAND									
12 NAP OF EARTH		87† 5 KNOTS 92† ? KNOTS							

NOTES: ** ROTOR BANG EXCESSIVE FOR THIS DATA † ONE DATA SAMPLE ONLY

C-1611D/AIC

TABLE C-7

AIRCRAFT UH-1H SERIAL NO. 71-20223 FLIGHT DATES 21 DEC 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF		93							
2 CLIMB		94/94*†		91/90*	92	.77	.99		
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		93†/92*		/87*	90/93*	.72/.76*	.99/.99*		1500
8 LEVEL FLIGHT	94	94	82	89	91	.72	.99	12	
9 HOVER AT ALTITUDE		93†	82					11	
10 HOVER/GND EFFECT		93†	87	90				6	
11 LAND									
12 NAP OF EARTH									

NOTES: * MAX. PERFORMANCE MANEUVER † ONE DATA SAMPLE ONLY NO AIC DATA

TABLE C-8

AIRCRAFT UH-IH SERIAL NO. 71-20228 FLIGHT DATES 14 Jan 77 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		92	87	87	87	.51	98	5	3000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		93	90	90	89	.54	98	3	2500
8 LEVEL FLIGHT	94	93	86	87	88			7	
9 HOVER AT ALTITUDE		91†	86	87					
10 HOVER/GND EFFECT		93	87	87				6	
11 LAND									
12 NAP OF EARTH		92†		89					

NOTES: † ONE DATA SAMPLE ONLY

C-6533/AIC

TABLE C-9

AIRCRAFT UH-IH SERIAL NO. 71-20254 FLIGHT DATES SEP OR OCT 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		94	78	78	84	.65	99	16	1200
3 DESCEND RIGHT		96	80	81	86	.68	99	16	1200
4 CLIMB LEFT		93	76	79	85	.66	99	17	1200
5 DESCEND LEFT		95 †	78					17	
6 CLIMB RIGHT		94 †	77					17	
7 DESCEND		96	80	80	86			16	
8 LEVEL FLIGHT	94	95	79	79	86	.77	99	16	
9 HOVER AT ALTITUDE		90 †	75					15	
10 HOVER/GND EFFECT		90 †	76					14	
11 LAND									
12 NAP OF EARTH		90 †	76	WINDOWS CLOSED				14	
		91 †	78	WINDOWS OPEN				13	
		95 †	83	WINDOWS, DOORS OPEN 30 KTS				12	
		96 †	87	WINDOWS, DOORS OPEN 60 KTS				9	

NOTES: † ONE DATA SAMPLE ONLY C-6533/AIC

TABLE C-10

AIRCRAFT UH-1H SERIAL NO. 73-21693 FLIGHT DATES 17 DEC 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		95/93* †	82/79* †	79	86	.86	99	13/14* †	2500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		99	87	83*	90	.70	99	12	1500
8 LEVEL FLIGHT	98	96	82	86	87	.73	99	14	
9 HOVER AT ALTITUDE		94	78	78				16	
10 HOVER/GND EFFECT		94	81	79				13	
11 LAND									
12 NAP OF EARTH									

NOTES: * MAX. PERFORMANCE MANEUVER † ONE DATA SAMPLE ONLY

C-6533/AIC

TABLE C-11

AIRCRAFT OH-58 SERIAL NO. 71-20475 FLIGHT DATES 3 DEC 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		92	81	81	86	.64	99	11	1600
3 DESCEND RIGHT									
4 CLIMB LEFT		94*	79*					15	
5 DESCEND LEFT		93*	82*	84*	86*	.50*	97*	11	1500
6 CLIMB RIGHT									
7 DESCEND		93	81	83	86	.61	98	12	1500
8 LEVEL FLIGHT	91	92		83	86	.61	98		
9 HOVER AT ALTITUDE		92	80	82	86	.62	98	12	1800
10 HOVER/GND EFFECT		92†		82					
11 LAND		92†		82					
12 NAP OF EARTH									

NOTES: * MAX. PERFORMANCE MANEUVER † ONE DATA POINT ONLY

TABLE C-12

AIRCRAFT OH-58 SERIAL NO. 71-20558 FLIGHT DATES OCT 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		91	91	88	90	.62	98	0	3000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		89	90	87				-1	
8 LEVEL FLIGHT		89	89	87	89	.60	98	0	
9 HOVER AT ALTITUDE		88				.59	98		
10 HOVER/GND EFFECT		91				.58	98		
11 LAND									
12 NAP OF EARTH		88† DOORS OFF							

NOTES: † ONE DATA SAMPLE ONLY

TABLE C-13

AIRCRAFT OH-58 SERIAL NO. 71-20561 FLIGHT DATES SEP OR OCT 76 CALIB: 250~ NO 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		86							
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT		85†							
7 DESCEND		86							
8 LEVEL FLIGHT		87							
9 HOVER AT ALTITUDE		85							
10 HOVER/GND EFFECT		86							
11 LAND									
12 NAP OF EARTH									

NOTES: CALIBRATION-TONE LEVEL ASSUMED SAME AS FOR TAPE OH-58 #20558 † ONE DATA SAMPLE ONLY

TABLE C-14

AIRCRAFT OH-58 SERIAL NO. 71-20563 FLIGHT DATES SEP OR OCT 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF		93†	87						
2 CLIMB		93	88	92	96	.66	99	5	1800
3 DESCEND RIGHT		94	89	92	97	.64	99	5	
4 CLIMB LEFT		93	86	90	92	.49	97	7	1800
5 DESCEND LEFT		94	87	91				7	
6 CLIMB RIGHT		94	87	92				7	
7 DESCEND		92	87	92	93	.48	97	5	
8 LEVEL FLIGHT	94	93	87	90				6	
9 HOVER AT ALTITUDE		93†	84					9	
10 HOVER/GND EFFECT		92†	86					6	
11 LAND									
12 NAP OF EARTH									

NOTES: † ONE DATA SAMPLE ONLY

TABLE C-15

AIRCRAFT OH-58 SERIAL NO. 71-20564 FLIGHT DATES 22 DEC 76 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF		92	85						
2 CLIMB		92/92*	83/82*	81/82*	84/84*	/.53*	/98*	9/10	/2000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		91/91*	83/83*	/82*	/84*	/.53*	/.98*	8/8	/1800
8 LEVEL FLIGHT		92	82	83	85	.51	98	10	
9 HOVER AT ALTITUDE		91	84	81	83	.53	98	7	1800
10 HOVER/GND EFFECT		92	82	83				10	
11 LAND									
12 NAP OF EARTH									

NOTES: * MAXIMUM PERFORMANCE MANEUVER † ONE DATA POINT ONLY

TABLE C-16

AIRCRAFT OH-58 SERIAL NO. 73-20549 FLIGHT DATES 16 DEC 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		97†	85	86	88	.50	97	12	2000
3 DESCEND RIGHT									
4 CLIMB LEFT		96†			88				
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		96†		88	90				
8 LEVEL FLIGHT	98	99†	87	87	89	.46	96	12	
9 HOVER AT ALTITUDE		97†	85	88				12	
10 HOVER/GND EFFECT		97†	85	87				12	
11 LAND									
12 NAP OF EARTH									

NOTES: † ONE DATA POINT ONLY

TABLE C-17

AIRCRAFT OV-ID SERIAL NO. 68-15933 FLIGHT DATES SEP OR OCT 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		96	84	86				12	
3 DESCEND RIGHT		100	85	87				15	
4 CLIMB LEFT		96	83	87				13	
5 DESCEND LEFT		99	86	89				13	
6 CLIMB RIGHT		96	84	87				12	
7 DESCEND		97	80	89				17	
8 LEVEL FLIGHT	97	98	85	90	91	.53	98	13	1600
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES:

TABLE C-18

AIRCRAFT OV-1D SERIAL NO. 68-15950 FLIGHT DATES 6 DEC 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF		116†	111					5	
CLIMB AFTER T/O		105†	102					3	
2 CLIMB		99	93	94	95	.53	98	6	
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		102	89	89	89	.43	94	13	2000
8 LEVEL FLIGHT	102	100	88	87	89			12	
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES: † ONE DATA SAMPLE ONLY

TABLE C-19

AIRCRAFT OV-1D SERIAL NO. 68-15959 FLIGHT DATES SEP OR OCT 76 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		104	94	96				10	
3 DESCEND RIGHT		102	87	94				15	
4 CLIMB LEFT		103	94	94				9	
5 DESCEND LEFT		102	89	93				13	
6 CLIMB RIGHT		104	94	96				10	
7 DESCEND		102	90	94				12	
8 LEVEL FLIGHT	98	102	88	95	95	.40	93	14	1600
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES:

TABLE C-20

AIRCRAFT OV-1D SERIAL NO. 68-16996 FLIGHT DATES 22 OCT 76, 12 NOV 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		103	97	97	102			6	
3 DESCEND RIGHT									
4 CLIMB LEFT		103							
5 DESCEND LEFT		105	96	94		.27	72	9	1200
6 CLIMB RIGHT									
7 DESCEND		105	92	92		.27	72	13	2000
8 LEVEL FLIGHT		104	94	93	95	.35	88	10	1600
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND		90†							
12 NAP OF EARTH									

NOTES: ONE 40 SEC. SECTION AT 106 dBA ON TAKE OFF. † ONE DATA SAMPLE ONLY

TABLE C-21

AIRCRAFT OV-1D SERIAL NO. 68-16997 FLIGHT DATES 13 OCT 76 12 NOV 76 CALIB: 250~ YES 1000~ NOT USABLE

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		99	92	89	91	.64	99	7	2000
3 DESCEND RIGHT		100	94	92				6	
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		100	86	89	94	.52	98	14	1800
8 LEVEL FLIGHT	102	100	94	91	92	.49	97	6	2000
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND		100 †							
12 NAP OF EARTH									

NOTES: † ONE DATA SAMPLE ONLY

TABLE C-22

AIRCRAFT OV-1D SERIAL NO. 69-17005 FLIGHT DATES 16 DEC 76 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		109	90	86	89			19	
3 DESCEND RIGHT		97	72					25	
4 CLIMB LEFT		109†	90					19	
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		98	75	76	78	.40	93	23	1800
8 LEVEL FLIGHT	101	100	79	77	80			21	
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES: PROPELLER SYNCRONIZATION PHASE EQUIPMENT NOT WORKING. † ONE DATA SAMPLE ONLY.

TABLE C-23

AIRCRAFT AH-1S SERIAL NO. 68-15177 FLIGHT DATES 19 JAN 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		97	83	87	86	.53	97	14	2500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		96	83	86	85	.46	96	13	2500
8 LEVEL FLIGHT	91	95	82	85	85	.47**	96	13	2500
9 HOVER AT ALTITUDE		90	78	81				12	
10 HOVER/GND EFFECT		92	84	84				8	
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .58 WITH 8.5 dB AGC CORRECTION

TABLE C-24

AIRCRAFT AH-1S SERIAL NO. 70-16010 FLIGHT DATES 17 JAN 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		91	86	85	85	.69	99	5	2000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		92	88	87	89	.63	99	4	2000
8 LEVEL FLIGHT	92	92	85	87	87	.64**	99	7	2000
9 HOVER AT ALTITUDE		89	85	85				4	
10 HOVER/GND EFFECT		89	83	84				6	
11 LAND									
12 NAP OF EARTH		89+		83					

NOTES: +One Data Sample for each entry

**A.I. = .64 With 3.1 dB AGC Correction

TABLE C-25

AIRCRAFT AH-1S SERIAL NO. 70-16038 FLIGHT DATES 26 JAN 77 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		95	87	91	90	.58	98	8	2500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		95	91	90	89	.59	98	4	2000
8 LEVEL FLIGHT	93	96	88	89	89	.71	99	7	2500
9 HOVER AT ALTITUDE		93	85	86				8	
10 HOVER/GND EFFECT		94	89	89				5	
11 LAND									
12 NAP OF EARTH		93^{+}		86					

NOTES: $^{+}$One data sample for each entry

TABLE C-26

AIRCRAFT AH-1S SERIAL NO. 71-20988 FLIGHT DATES 25 JAN 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	∆dBA	Hz
1 TAKE OFF									
2 CLIMB		96	89	86	87			7	2300
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		97	89	88	89	.66	99	8	2200
8 LEVEL FLIGHT	94	97	89	89	90	.57	98	8	2200
9 HOVER AT ALTITUDE		95	86	86				9	
10 HOVER/GND EFFECT		96	87	87				9	
11 LAND									
12 NAP OF EARTH		96†		86†					

NOTES: † ONE DATA SAMPLE ONLY

TABLE C-27

AIRCRAFT AH-1Q SERIAL NO. 68-15209 FLIGHT DATES 28 JAN 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		94	84	83	85	.60	98	10	2500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		95	86	85	87	.77	99	9	2500
8 LEVEL FLIGHT	95	95	87	87	86	.61**	99	8	2500
9 HOVER AT ALTITUDE		92	82	83				10	
10 HOVER/GND EFFECT		93	82	83				11	
11 LAND									
12 NAP OF EARTH		94+		85					

NOTES: +One data sample for each entry

**A.I. = .64 with 3.0 dB AGC Correction

TABLE C-28

AIRCRAFT AH-1Q SERIAL NO. 70-15945 FLIGHT DATES 21 JAN 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		94	87	85	89	.68	99	7	2000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		94	85	87	89	.61	99	9	2000
8 LEVEL FLIGHT	94	95	87	87	90	.64**	99	7	2000
9 HOVER AT ALTITUDE		92	81	86				11	
10 HOVER/GND EFFECT		92	84	84				8	
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .72 with 5.1 dB AGC Correction

TABLE C-29

AIRCRAFT CH-47C SERIAL NO. 70-15003 FLIGHT DATES 9 FEB 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		110	92	92	91	.27	71	18	2000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		111	92	94	91	.20	49	19	2000
8 LEVEL FLIGHT	114	111	92	92	91	.33**	83	19	2000
9 HOVER AT ALTITUDE		111	92	91				19	
10 HOVER/GND EFFECT		112	93	92				19	
11 LAND									
12 NAP OF EARTH									

NOTES: Top of Ramp Door Open During Flight

**A.I. = .39 with 3.0 dB AGC Correction

TABLE C-30

AIRCRAFT CH-47C SERIAL NO. 70-15020 FLIGHT DATES 31 JAN 77 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		109	91	91	91			18	1700
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		109	93	94	93			16	
8 LEVEL FLIGHT	115	108	93	93	93			15	
9 HOVER AT ALTITUDE		109	92	93				17	
10 HOVER/GND EFFECT		109	92	91				17	
11 LAND									
12 NAP OF EARTH									

NOTES: RETURN TO BASE: LEVEL IN EARCUP SOMETIMES RISES TO 107-116 dBA FOR 5 SECONDS

TABLE C-31

AIRCRAFT CH-47C SERIAL NO. 70-15026 FLIGHT DATES 7 FEB 77 CALIB: 250~ YES 1000~ NO

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		111	91	93	91			20	
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		112	94	92	93			18	
8 LEVEL FLIGHT	114	112	92	95	92			20	
9 HOVER AT ALTITUDE		110	90	91				20	
10 HOVER/GND EFFECT		111	92	90				19	
11 LAND									
12 NAP OF EARTH									

NOTES: LEVEL IN EARCUP RISES TO 105 dBA FOR 10 SECONDS ON RETURN TO BASE

TABLE C-32

AIRCRAFT CH-54B SERIAL NO. 69-18465 FLIGHT DATES 8 APR 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		96	84	85	88	.57	98	11	2200
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		96	81	83	86	.51	97	15	2200
8 LEVEL FLIGHT	96	95	84	85	86	.54**	97	11	2200
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .55 with 0.7 dB AGC Correction

TABLE C-33

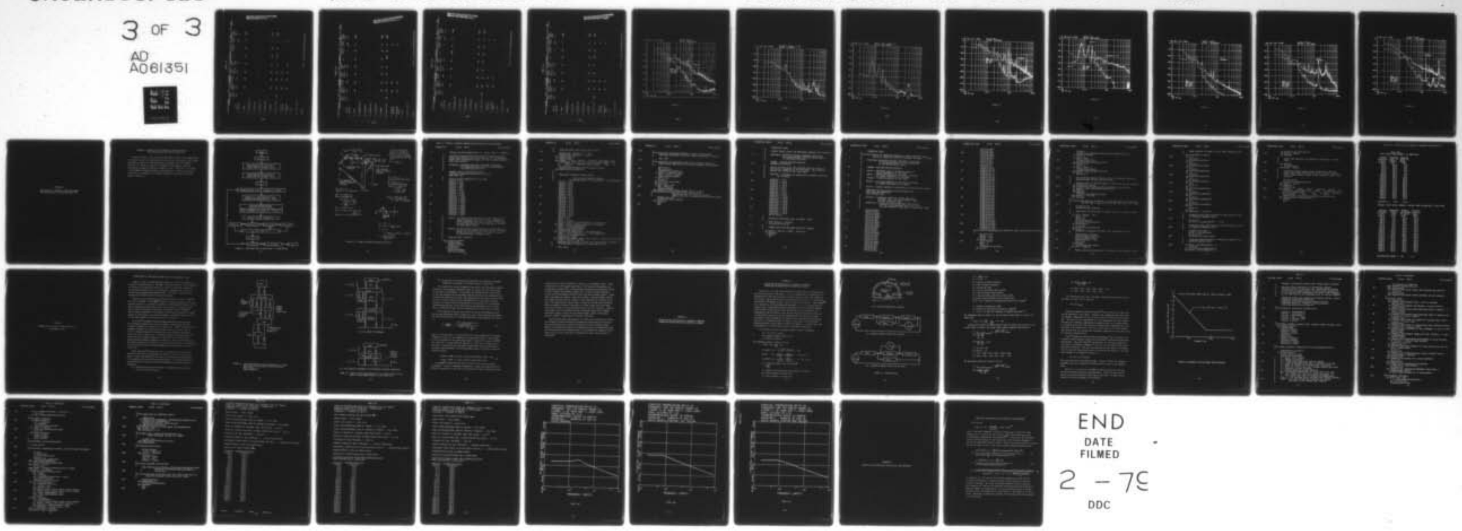
AIRCRAFT CH-54B SERIAL NO. 69-18468 FLIGHT DATES 1 APR 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		93	81	84		.50	97	12	2000
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		93	83	82		.60	98	10	
8 LEVEL FLIGHT	97	93	84	83	87	.58**	98	9	2000
9 HOVER AT ALTITUDE									
10 HOVER/GND EFFECT									
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .61 with 0.6 dB AGC Correction

AD-A061 351 VOUGHT CORP ADVANCED TECHNOLOGY CENTER INC DALLAS TEX F/G 1/3
ANALYSIS OF NOISE IN US ARMY AIRCRAFT.(U)
NOV 78 A J BROUNS, R A ELY DAAB07-76-C-1746
UNCLASSIFIED ATC-94100/8CR-41 USAAVRADCOM-TR-76-1746-F NL

3 OF 3
AD
A061351



END
DATE
FILMED
2 -79
DDC

TABLE C-34

AIRCRAFT CH-54B SERIAL NO. 69-18470 FLIGHT DATES 15 APR 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		96	86	90	91	.37	90	10	1500
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		96	87	90	91	.35	88	9	1200
8 LEVEL FLIGHT	96	96	87	90	91	.42**	94	9	2400
9 HOVER AT ALTITUDE		98	93	96				5	
10 HOVER/GND EFFECT		98	90	97	94			8	
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .50 with 3.9 dB AGC Correction

TABLE C-35

AIRCRAFT CH-54B SERIAL NO. 69-18473 FLIGHT DATES 31 MAR 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		98	85	93	90	.40	93	13	1800
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		98	84	90	91	.37	90	14	1800
8 LEVEL FLIGHT	102	99	82	90	91	.46**	96	17	1800
9 HOVER AT ALTITUDE		101	88					13	
10 HOVER/GND EFFECT		102	89					13	
11 LAND									
12 NAP OF EARTH									

NOTES: ** A.I. = .62 with 7.4 dB AGC Correction

TABLE C-36

AIRCRAFT CH-54B SERIAL NO. 69-18476 FLIGHT DATES 13 APR 77 CALIB: 250~ YES 1000~ YES

	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		101	91	98	96	.38**	91	10	1600
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		102	89	90	96	.63	98	13	1600
8 LEVEL FLIGHT	103	103	90	97	97	.53	97	13	1600
9 HOVER AT ALTITUDE		98	93					5	
10 HOVER/GND EFFECT		96	91					5	
11 LAND									
12 NAP OF EARTH									

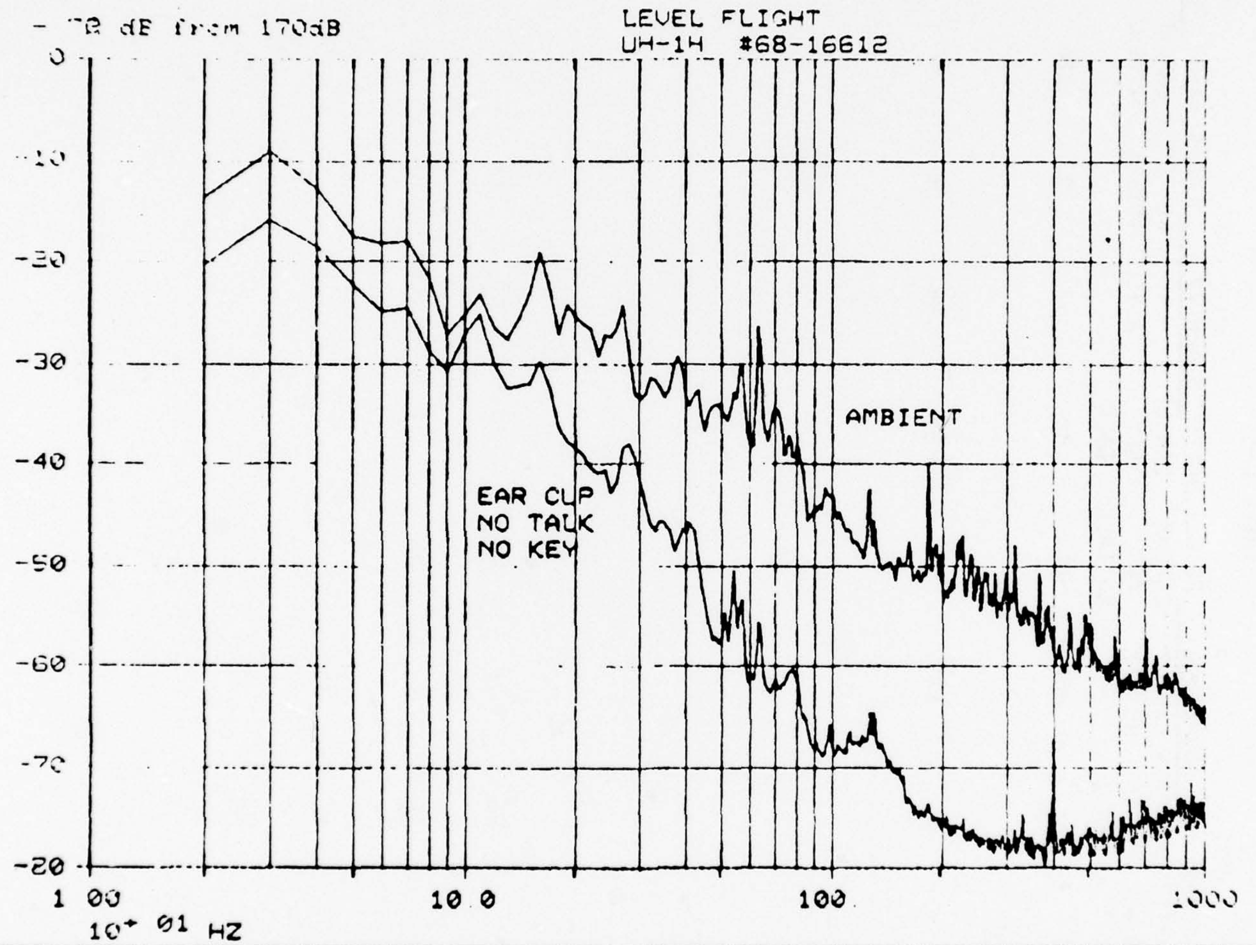
NOTES: **A.I. = .44 with 1.7 dB AGC Correction

TABLE C-37

AIRCRAFT CH-54B SERIAL NO. 69-18490 FLIGHT DATES 8 APR 77 CALIB: 250~ YES 1000~ YES

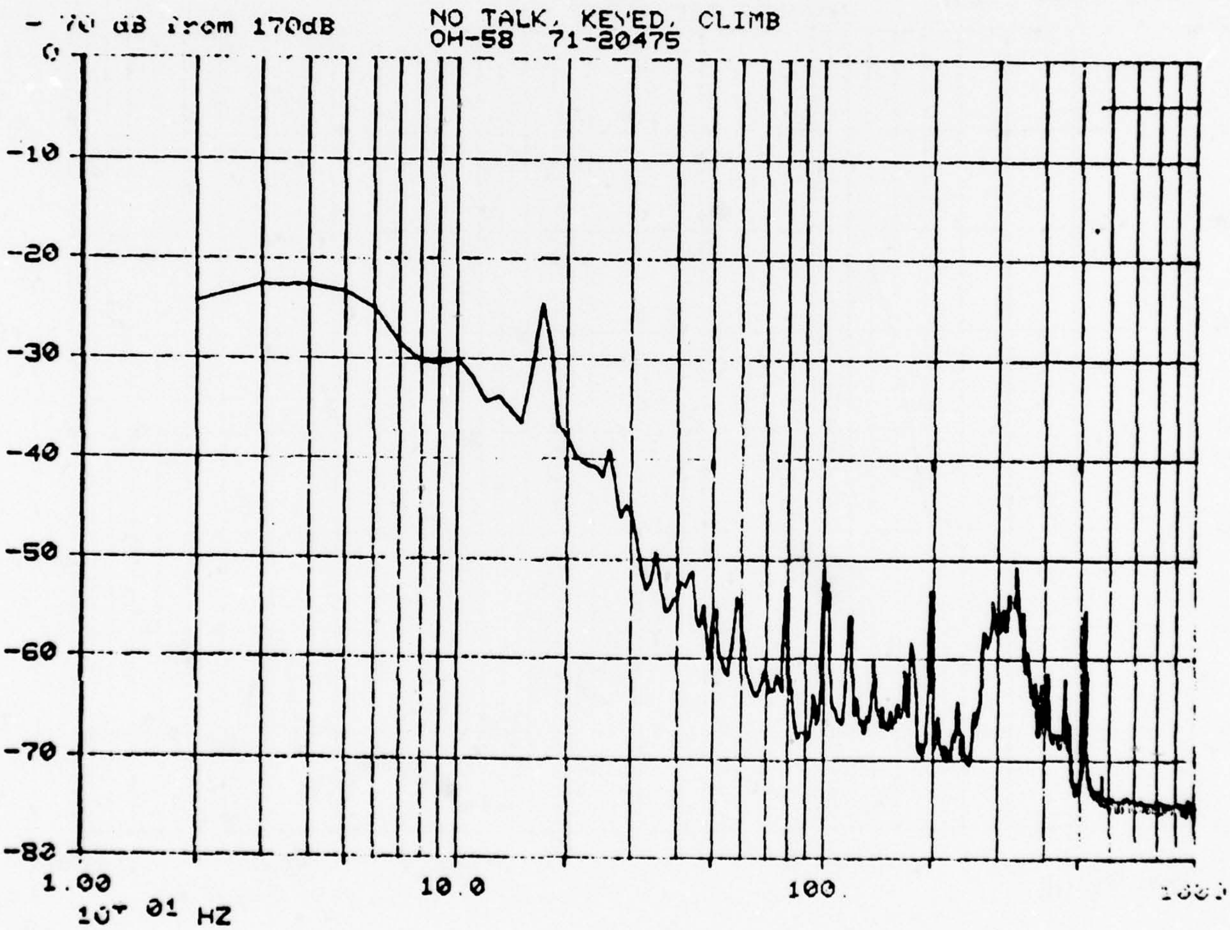
	COCKPIT SLM "SLOW"	COCKPIT AMBIENT CHAN 2	EARCUP NO KEY	EARCUP KEY NO TALK	EARCUP KEY TALK	A.I.	SENTENCE INTELL.	EARCUP ATTEN.	NOISE CROSS-OVER
UNITS	dBA	dBA	dBA	dBA	dBA		%	ΔdBA	Hz
1 TAKE OFF									
2 CLIMB		92	84	91	91	.46	96	8	1800
3 DESCEND RIGHT									
4 CLIMB LEFT									
5 DESCEND LEFT									
6 CLIMB RIGHT									
7 DESCEND		96	83	89	90	.43	95	13	1800
8 LEVEL FLIGHT	96	95	83	89	91	.45**	96	12	1800
9 HOVER AT ALTITUDE		95	86					9	
10 HOVER/GND EFFECT		96	82					14	
11 LAND									
12 NAP OF EARTH									

NOTES: **A.I. = .51 with 2.6 dB AGC Correction



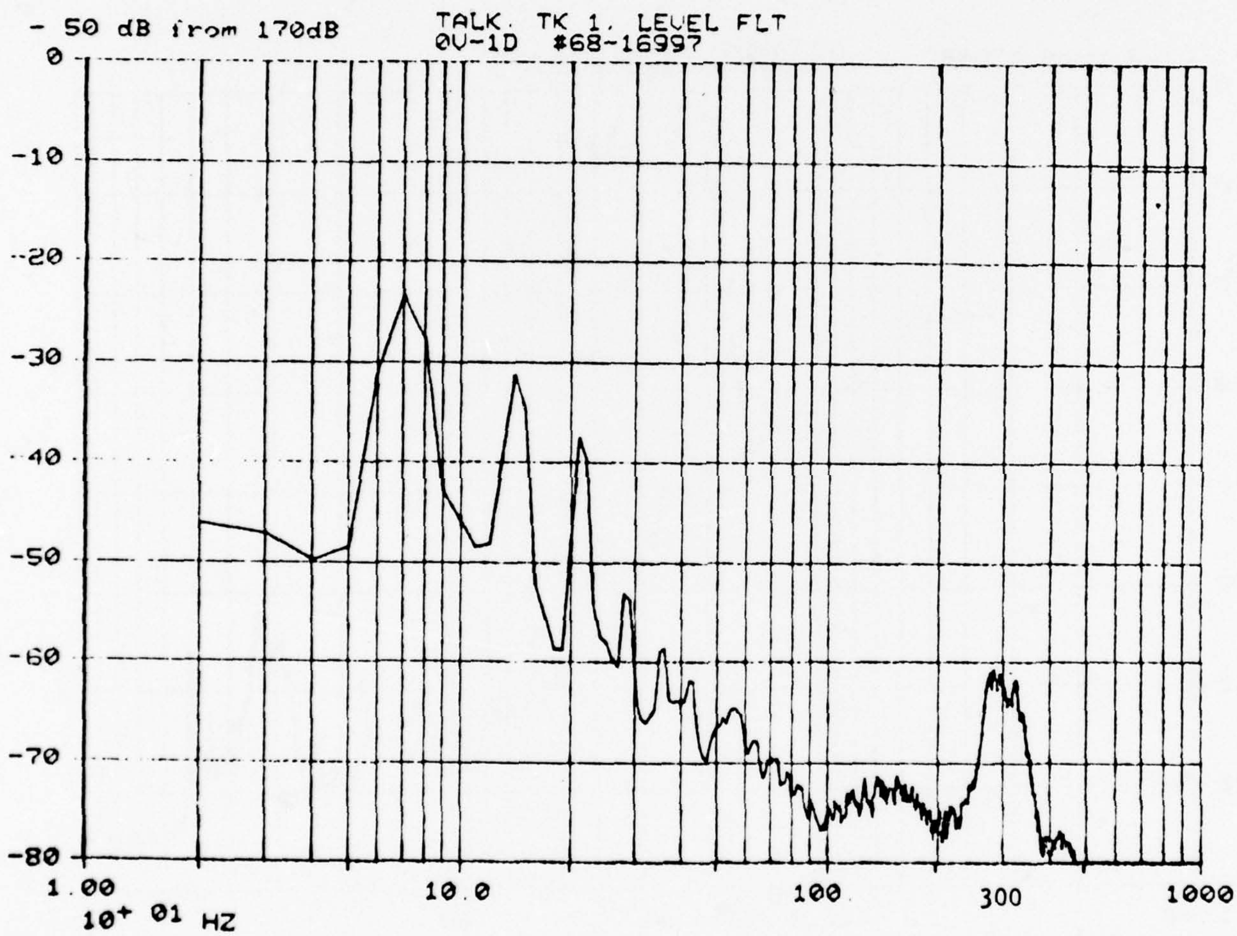
- 70 dB from 170dB
LEVEL FLIGHT
UH-1H #68-16612
AMBIENT
EAR CUP
NO TALK
NO KEY
1 00
10.0
100
1000
10+ 01 HZ

FIGURE C-1



- 70 dB from 170dB
NO TALK, KEYED, CLIMB
OH-58 71-20475
0
-10
-20
-30
-40
-50
-60
-70
-80
1.00
10.0
100.
10↑ 01 HZ

FIGURE C-2



- 50 dB from 170dB
TALK. TK 1. LEVEL FLT
0V-1D #68-16997
0
-10
-20
-30
-40
-50
-60
-70
-80
1.00
10.0
100
300
1000
10+ 01 HZ

FIGURE C-3

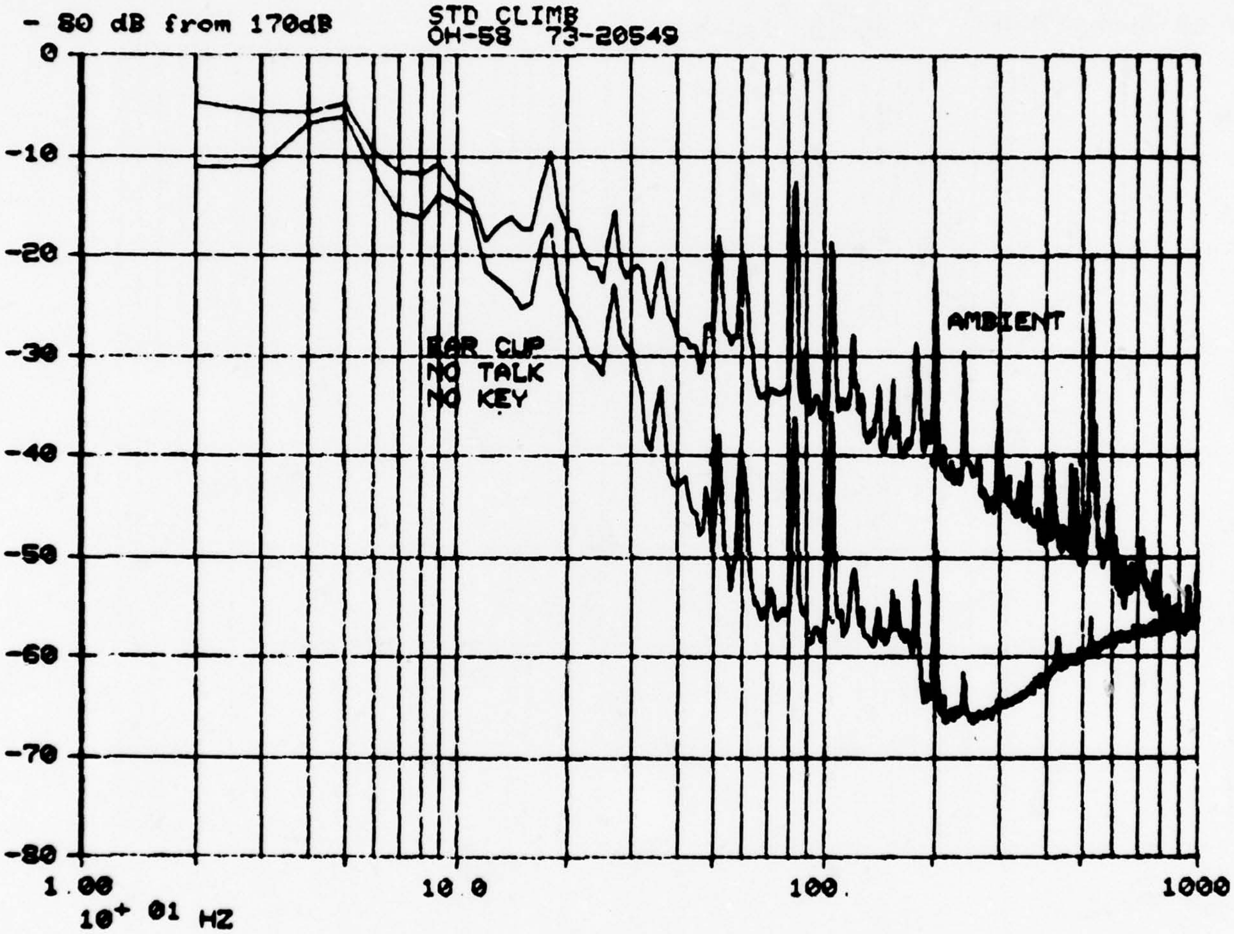

- 80 dB from 170dB
STD CLIMB
OH-58 73-20549
0
-10
-20
-30
-40
-50
-60
-70
-80
EAR CUP
NO TALK
NO KEY
AMBIENT
1.00
10+ 01 HZ
10.0
100.
1000

FIGURE C-4

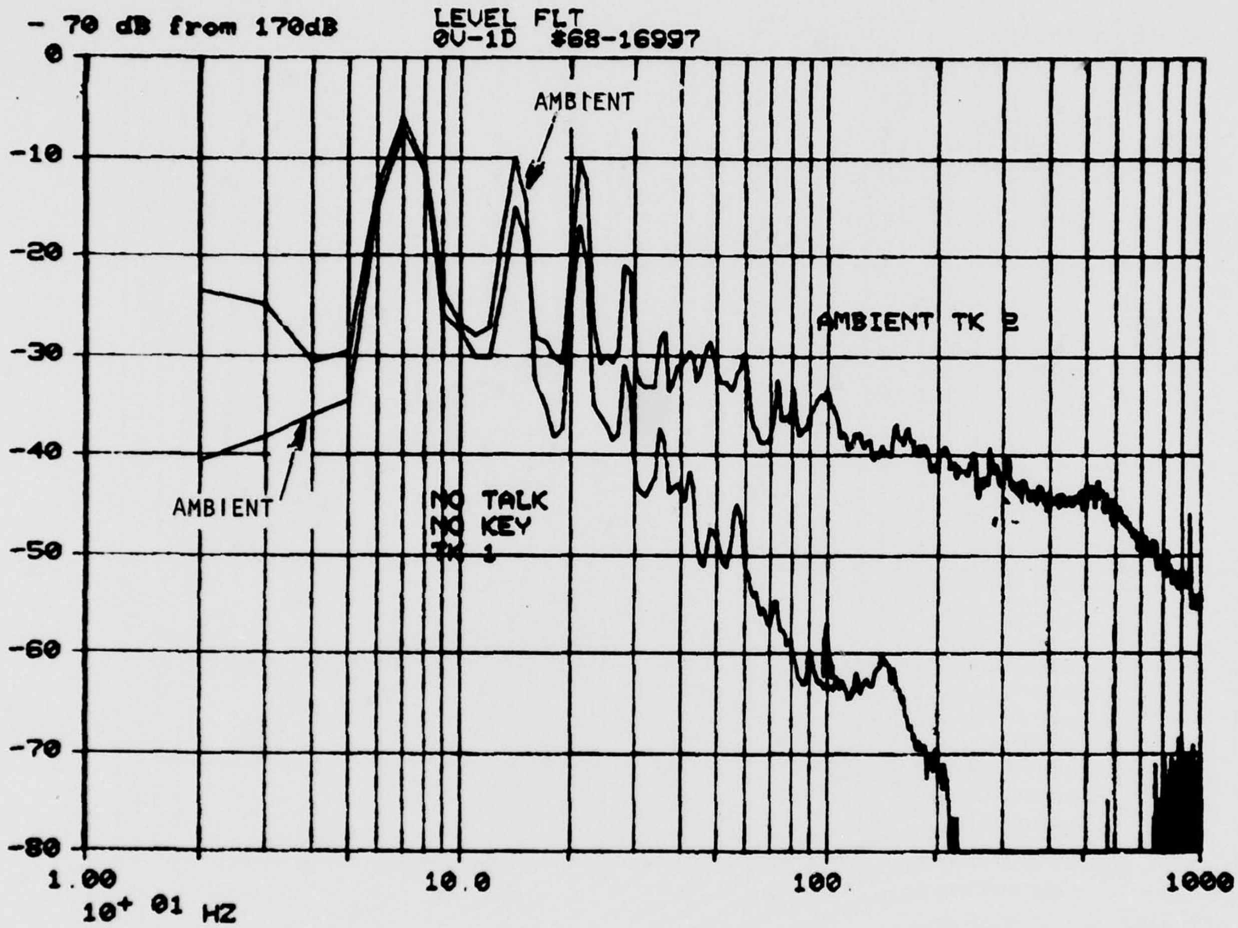
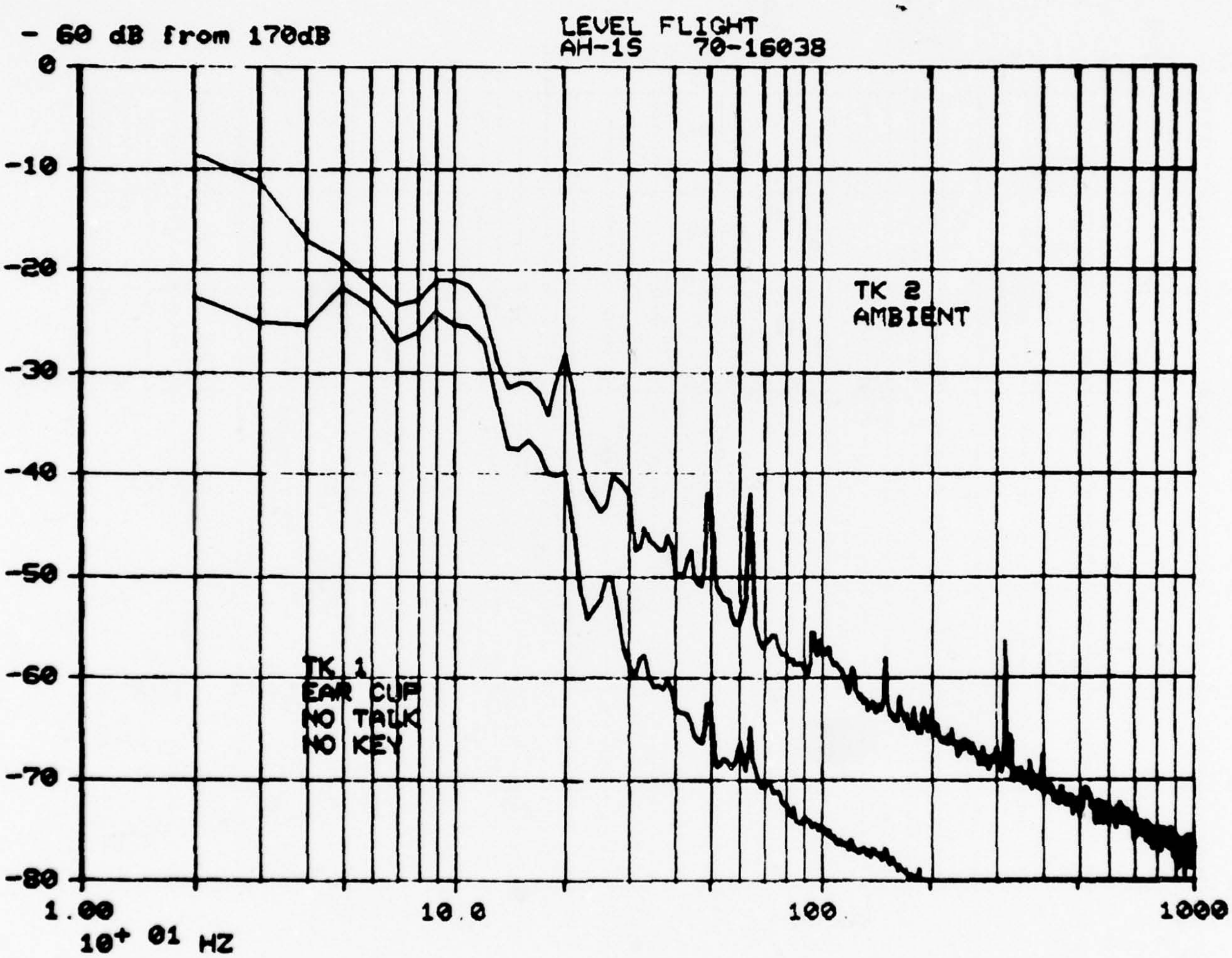
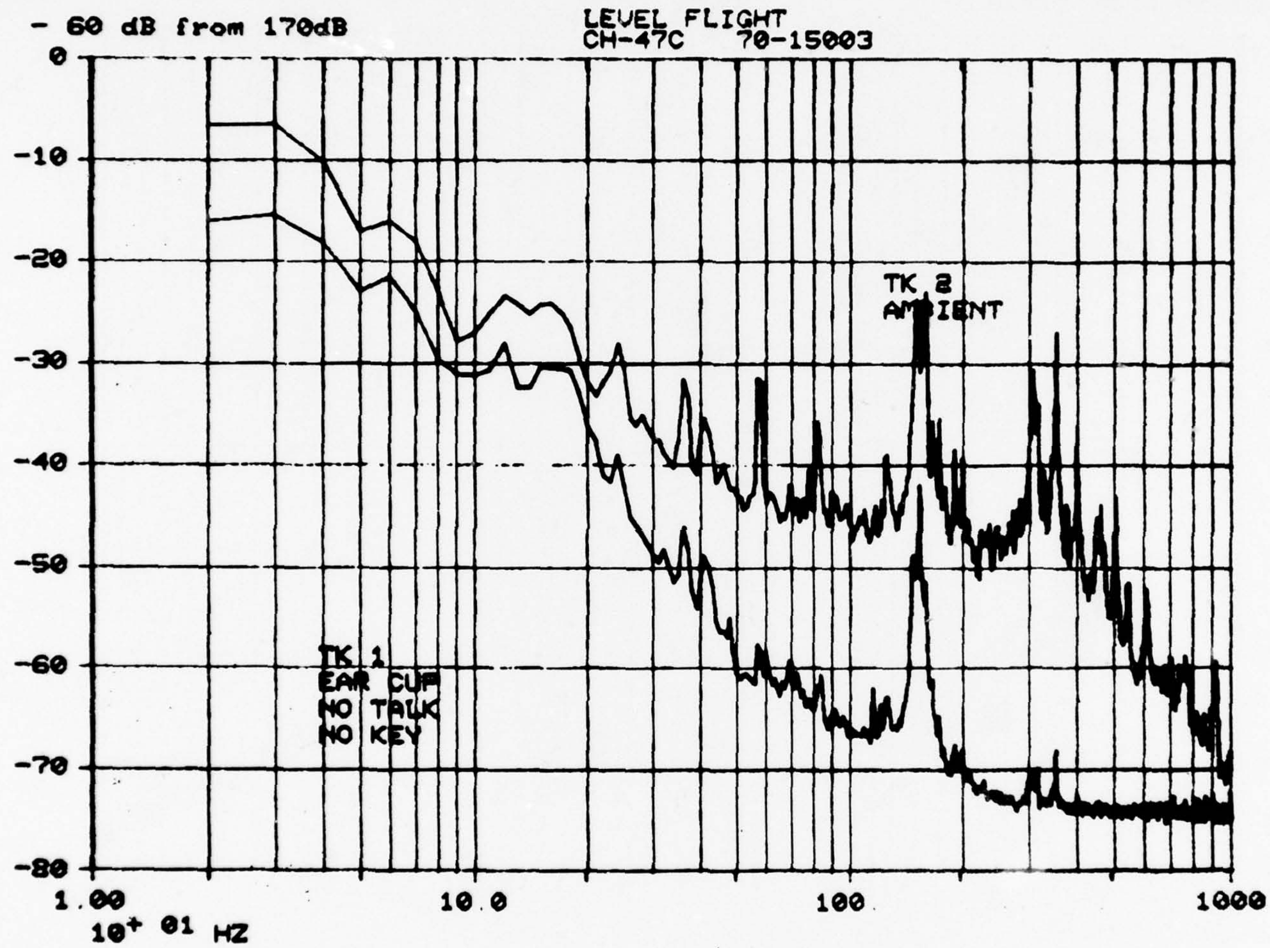

- 70 dB from 170dB
LEVEL FLT
OV-1D #68-16997
AMBIENT
AMBIENT TK 2
AMBIENT
NO TALK
NO KEY
TK 1
0
-10
-20
-30
-40
-50
-60
-70
-80
1.00
10.0
100
1000
10+ 01 HZ

FIGURE C-5



- 60 dB from 170dB
LEVEL FLIGHT
AH-1S 70-16038
0
-10
-20
-30
-40
-50
-60
-70
-80
1.00
10.0
100
1000
10+ 01 HZ
TK 2
AMBIENT
TK 1
EAR CUP
NO TALK
NO KEY

FIGURE C-6



- 60 dB from 170dB
LEVEL FLIGHT
CH-47C 70-15003
0
-10
-20
-30
-40
-50
-60
-70
-80
1.00
10.0
100
1000
10+ 01 HZ
TK 2
AMBIENT
TK 1
EAR CUP
NO TALK
NO KEY

FIGURE C-7

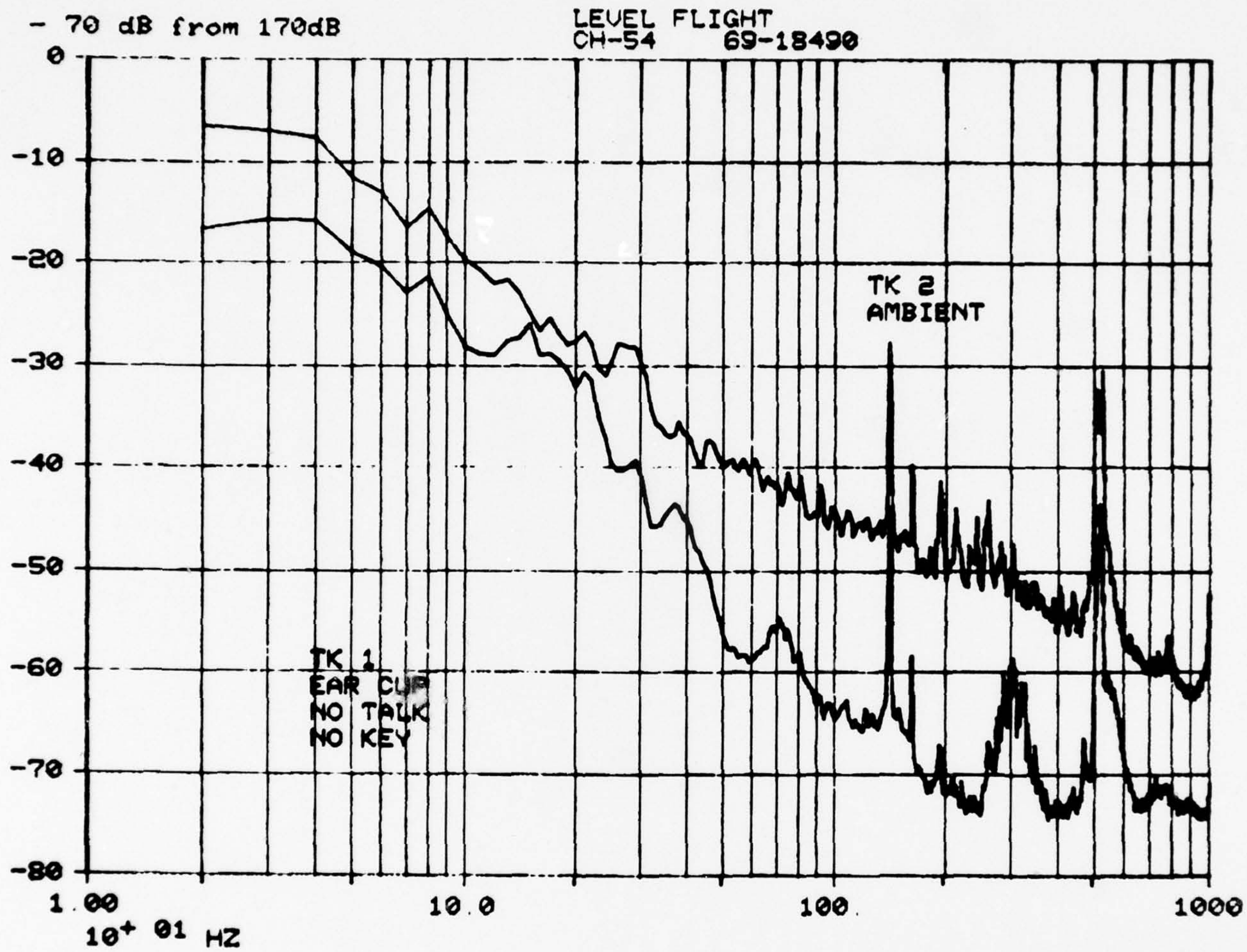

- 70 dB from 170dB
LEVEL FLIGHT
CH-54 69-18490
0
-10
-20
-30
-40
-50
-60
-70
-80
TK 2
AMBIENT
TK 1
EAR CUP
NO TALK
NO KEY
1.00
10.0
100.
1000
10+ 01 HZ

FIGURE C-8

APPENDIX D

DESCRIPTION OF A FORTRAN IV COMPUTER PROGRAM FOR CALCULATIONS OF ARTICULATION INDEX (AI)

APPENDIX D DESCRIPTION OF A FORTRAN IV COMPUTER PROGRAM FOR CALCULATIONS OF ARTICULATION INDEX (AI)

Figure D-1 shows a flow chart which describes the logic of the computerized AI calculations which were completed during the studies described in this report. That logic is based on an American National Standards Institute standard ANSI S3.5.[19] Figure D-2 shows the trigonometric and algebraic bases for calculating the degree of masking of speech by noise. Table D-1 is a listing of the FORTRAN IV computer program for calculating AI. Results of a typical calculation, corresponding to an example presented in ANSI S3.5,[19] are presented in Table D-2.

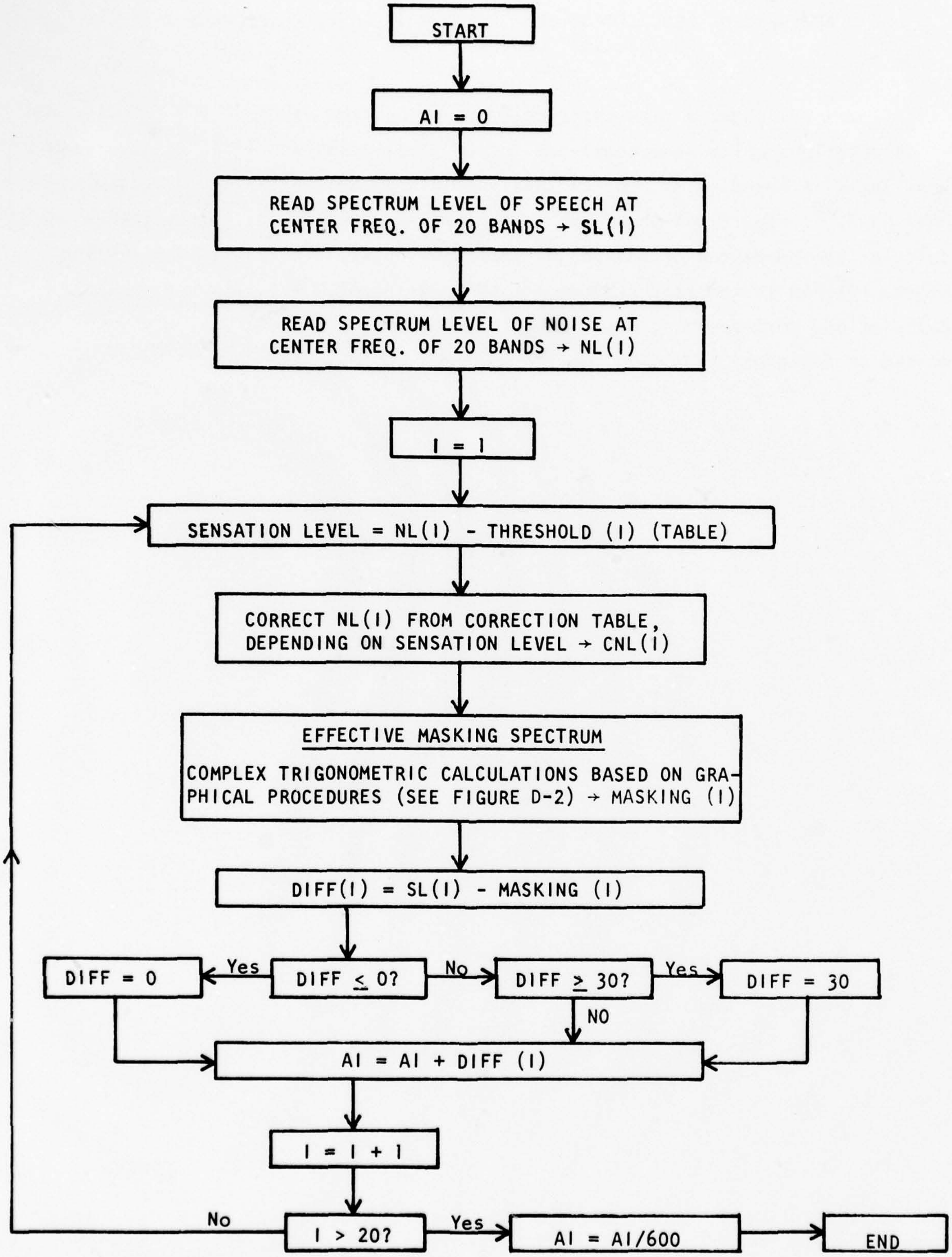
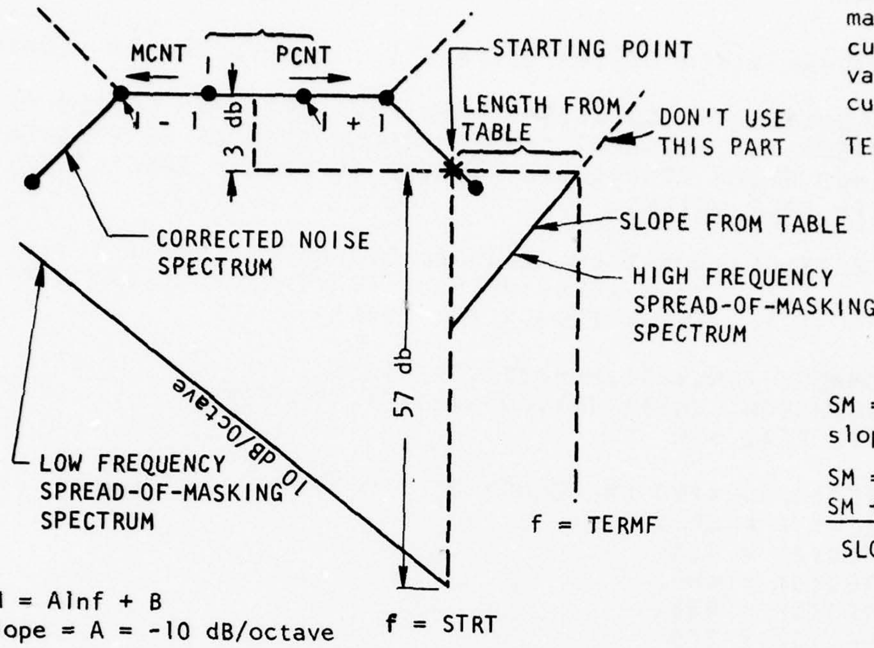


FIGURE D-1. FLOW CHART FOR AI CALCULATIONS - 20 BAND METHOD.

$$f_{max}(I) = \sqrt{f_{max} \cdot f_{min}}$$



If there are several maxima, all spread-of-masking curves are calculated, and the maximum values comprise the final curve.

$TEST = NR_{max} - 3$

$SM = A\ln f + B$
Slope $= A = -10$ dB/octave

$$\begin{aligned} SM + 10 &= A\ln f + B \\ \underline{SM} &\underline{= A\ln 2f + B} \end{aligned}$$

$$\begin{aligned} 10 &= A(\ln f - \ln 2f) \\ &= A\ln 1/2 = .693A \\ A &= \frac{-10}{.693} = 14.43 \end{aligned}$$

$SM = -14.43 \ln f + B$

when $f = STRT$, $SM = NR_{max} - 60$
$= TEST - 57$

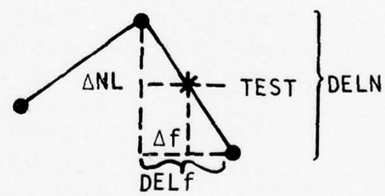
$TEST - 57 = -14.43 \ln(STRT) + B$

$SM = C\ln f + D$
slope = SLOPE (dB/octave)

$$\begin{aligned} SM &= C\ln f + D \\ \underline{SM + SLOPE} &\underline{= C\ln 2f + D} \end{aligned}$$

$$\begin{aligned} SLOPE &= C\ (\ln 2f - \ln f) \\ &= C\ln 2f/f \\ &= C\ln 2 = .693C \\ C &= SLOPE/.693 \end{aligned}$$

when $f = TERM$, $SM = TEST$
$TEST = C\ln(TERMF) + D$
$D = TEST - C\ln(TERMF)$



$NL = A\ln f + B$

$\Delta NL = \frac{\Delta f}{f}$; $A = \frac{f}{DELf}$ DELN

$\Delta f = \frac{f}{A} \Delta NL$

f = geometric center of interval

$$\Delta f = \frac{f_{mean}\ \Delta NL\ DELf}{f_{mean}\ DELN}$$

FIGURE D-2. SCHEME FOR COMPUTING SPREAD-OF-MASKING

TABLE D-1 FORTRAN IV COMPUTER PROGRAM FOR CALCULATING ARTICULATION INDEX

```
PROGRAM AI          74/74    OPT=1                         FTN 4.6+428

                 PROGRAM AI(INPUT,OUTPUT,TAPE 5 = INPUT, TAPE 6 = OUTPUT)
            C
            C    CALCULATE ARTICULATION INDEX FROM SPECTRUM LEVELS OF
            C    SPEECH AND NOISE AT CENTER FREQUENCIES OF 20 FREQUENCY
            C    BANDS WHICH CONTRIBUTE EQUALLY TO SPEECH INTELLIGIBILITY
            C    WITH MALE VOICES.
            C
            C    REFERENCE--AMERICAN NATIONAL STANDARDS INSTITUTE,
            C              S3.5/1969,*METHODS FOR THE CALCULATION OF
            C              THE ARTICULATION INDEX*
            C
                 COMMON/ /CNL(20),MSK(20),FREQ(20)
                 DIMENSION COMNT1(10),COMNT2(10),SPCH(20)
                 TYPE REAL MSK
            C
            C    FREQ(I)=CENTER FREQUENCY OF ITH BAND
                 FREQ(1) = 270.
                 FREQ(2) = 380.
                 FREQ(3) = 490.
                 FREQ(4) = 630.
                 FREQ(5) = 770.
                 FREQ(6) = 920.
                 FREQ(7) = 1070.
                 FREQ(8) = 1230.
                 FREQ(9) = 1400.
                 FREQ(10)  = 1570.
                 FREQ(11)  = 1740.
                 FREQ(12)  = 1920.
                 FREQ(13)  = 2130.
                 FREQ(14)  = 2370.
                 FREQ(15)  = 2660.
                 FREQ(16)  = 3000.
                 FREQ(17)  = 3400.
                 FREQ(18)  = 3950.
                 FREQ(19)  = 4560.
                 FREQ(20)  = 5600.
            C
            C    CNL(I)  IS READ AS THE SPECTRUM LEVEL OF NOISE AT THE
            C            CENTER FREQUENCY OF THE ITH BAND. SUBROUTINE
            C            CORCT INCREASES SOME NOISE LEVELS TO TAKE INTO
            C            ACCOUNT THE INCREASED EFFECTIVENESS OF MASKING
            C            AT HIGH SOUND LEVELS.
            C
            C    SPCH(I) IS READ AS THE LONG-TERM RMS SPECTRUM LEVEL OF
            C            SPEECH AT THE CENTER FREQUENCY OF THE ITH BAND.
            C            THOSE LEVELS ARE CONVERTED TO SPECTRUM LEVEL
            C            OF SPEECH PEAKS BY ADDING 12 DB.
            C
            C    READ AND WRITE COMMENTS
            C
             202 READ(5,1)COMNT1
               1 FORMAT(10A8)
                 READ(5,1)COMNT2
                 WRITE(6,2)
               2 FORMAT(1H1)
                 WRITE(6,1)COMNT1
                 WRITE(6,1)COMNT2
```

```
C
C     READ AND WRITE SPEECH AND NOISE LEVELS
C
      READ(5,100) (SPCH(I), I = 1,20)
      READ(5,100) (CNL(I), I = 1,20)
  100 FORMAT(10F8.2)
      WRITE(6,300)
  300 FORMAT( /,10X,* CENTER   SPECTRUM  SPECTRUM*,/,10X,
     1*FREQUENCY  LEVEL OF  LEVEL OF*,/,10X,*OF BAND     *,
     2       *SPEECH    NOISE*,/,10X,* (HERTZ)     (DB)      *,
     3*   (DB)*)
      WRITE(6,310)(FREQ(I),SPCH(I),CNL(I),I=1,20)
  310 FORMAT(10X,F8.1,2F10.1)
C
C
C     CALCULATE A-WEIGHTED SOUND LEVELS
C
C                   USE MSK FOR TEMPORARY STORAGE
C              FOLLOWING VALUES ARE A-WEIGHTING + 10LOG(DELTA F )
      MSK(1) = 13.4
      MSK(2) = 15.0
      MSK(3) = 17.6
      MSK(4) = 19.5
      MSK(5) = 20.0
      MSK(6) = 21.3
      MSK(7) = 21.9
      MSK(8) = 22.5
      MSK(9) = 23.1
      MSK(10) = 23.3
      MSK(11) = 23.4
      MSK(12) = 24.0
      MSK(13) = 24.7
      MSK(14) = 25.5
      MSK(15) = 26.4
      MSK(16) = 27.0
      MSK(17) = 27.6
      MSK(18) = 28.8
      MSK(19) = 29.9
      MSK(20) = 30.2
      ASPCH = 0.0
      ANOIS = 0.0
      DO 50 I = 1,20
      ASPCH = ASPCH + 10.0**((SPCH(I) + MSK(I))/10.)
   50 ANOIS = ANOIS + 10.0**((CNL(I)+ MSK(I))/10.)
      ASPCH = 10.0*ALOG10(ASPCH)
      ANOIS = 10.0*ALOG10(ANOIS)
      WRITE(6,400) ASPCH,ANOIS
  400 FORMAT(/,10X,*OASL(DBA) = *,F7.1,F10.1,/)
      ASPCH = 10.0**(ASPCH/10.) + 10.0**(ANOIS/10.)
      ASPCH = 10.0*ALOG10(ASPCH)
      WRITE(6,401) ASPCH
  401 FORMAT(10X,*OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100
     1,*HZ) = *,F5.1,* DBA*,/)
C     INCREASE NOISE LEVELS TO TAKE INTO ACCOUNT THE INCREASED
C     EFFECTIVENESS OF MASKING AT HIGH SOUND LEVELS.
C
      CALL CORCT
```

```
      C
      C*****CALCULATE SPREAD-OF-MASKING OF NOISE SPECTRUM,AND
      C     CALCULATE RESULTING EFFECTIVE MASKING SPECTRUM.  *******
      C
            CALL MASK
      C
      C*****CALCULATE ARTICULATION INDEX FROM SPECTRUM LEVELS OF
      C     SPEECH PEAKS AND FROM THE EFFECTIVE MASKING SPECTRUM****
      C
            SUM = 0.0
            DO 40 I=1,20
            IF(SPCH(I).GT.0.0)5,10
          5 SPCH(I) = SPCH(I) +12.0
            DIFF = SPCH(I) -MSK(I)
            IF(DIFF.GT.0.0)20,10
         10 DIFF = 0.0
            GO TO 40
         20 IF(DIFF.LT.30.)40,30
         30 DIFF =30.
         40 SUM = SUM + DIFF
            ART = SUM/600.
            WRITE(6,200)ART
        200 FORMAT( //,10X,*ARTICULATION INDEX = *,F4.2)
      C*****************ONE CARD AFTER EACH DATA SET.
      C                      CARD READS 999. IN FIRST 10 COLUMNS
      C                      AFTER LAST SET OF DATA************************
            READ(5,100) TEST
            IF(TEST.EQ.999.) 201,202
        201 CONTINUE
            STOP
            END
```

```
      SUBROUTINE CORCT
C
C     CORRECT NOISE LEVELS FOR NONLINEAR MASKING EFFECTIVENESS
C
C     REFERENCE--AMERICAN NATIONAL STANDARDS INSTITUTE,
C                S3.5/1969,*METHODS FOR THE CALCULATION OF
C                THE ARTICULATION INDEX*
C
      COMMON   CNL(20),MSK(20),FREQ(20)
      DIMENSION THRSH(20)
C
C     CNL(K) IS READ IN AS THE SPECTRUM LEVEL OF NOISE AT
C     THE CENTER FREQUENCY OF THE KTH BAND.  THE CORRECTED
C     VALUES ARE STORED IN THE SAME ARRAY
C
C     THRSH(K) = THRESHOLD OF AUDIBILITY AT CENTER FREQUENCY
C           OF KTH BAND
C
      THRSH(1) = -7.0
      THRSH(2) = -11.0
      THRSH(3) = -14.0
      THRSH(4) = -16.0
      THRSH(5) = -16.0
      THRSH(6)= -16.0
      THRSH(7) = -16.0
      THRSH(8) = -17.5
      THRSH(9) = -19.0
      THRSH(10) = -20.0
      THRSH(11) = -22.0
      THRSH(12) = -23.5
      THRSH(13) = -25.5
      THRSH(14) = -27.5
      THRSH(15) = -29.0
      THRSH(16) = -30.0
      THRSH(17) = -30.0
      THRSH(18) = -29.0
      THRSH(19) = -24.0
      THRSH(20) = -21.0
      DO 30 K=1,20
C
C     CALCULATE SENSATION LEVEL OF NOISE = SENT
C
    1 SENT =CNL(K) - THRSH(K)
      IF(SENT.GT.80)10,30
C
C     CORRECTIONS FOR NONLINEAR GROWTH OF MASKING
C
   10 CNL(K) = CNL(K) + (SENT - 80.0)/5.0
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MASK
C
C**********CALCULATE SPREAD-OF-MASKING OF NOISE SPECTRUM, AND
C           CALCULATE RESULTING EFFECTIVE MASKING SPECTRUM     *****
C
C     REFERENCE--AMERICAN NATIONAL STANDARDS  INSTITUTE,
C                S3.5-1969,*METHODS FOR THE CALCULATION
C                OF THE ARTICULATION INDEX*
C
      COMMON/ /CNL(20),MSK(20),FREQ(20)
C
C     CNL(K) = SPECTRUM LEVEL OF CORRECTED NOISE AT
C              CENTER FREQUENCY OF KTH BAND
C     MSK(K) = EFFECTIVE MASKING OF THE NOISE SPECTRUM
C              AT CENTER FREQUENCY OF KTH BAND
C     FREQ(K) = CENTER FREQUENCY OF KTH BAND
C
C     SOM(K) = SPREAD-OF-MASKING OF THE NOISE SPECTRUM
C              AT CENTER FREQUENCY OF KTH BAND
C
C     MAX(K) = IDENTIFICATION OF FREQUENCIES AT WHICH MAXIMA OCCUR
C
      DIMENSION MAX(20),SOM(20),EXT(5,7),SLOPE(5,7)
      TYPE REAL MAX,MERGF,MSK
      TYPE INTEGER PCNT
C
C     EXT(J,K) = NUMBER OF HERTZ TO EXTEND LINE FROM
C                STARTING POINT FOR JTH FREQUENCY RANGE
C                AND KTH AMPLITUDE RANGE
C     SLOPE(J,K) = SLOPE OF LINE (DB/OCTAVE) FROM END OF
C                  EXTENDED LINE(DOWNWARD AND TO THE LEFT)
C                  FOR JTH FREQUENCY RANGE AND KTH AMPLITUDE RANGE
C
      EXT(1,1)=250.
      EXT(2,1)=500.
      EXT(3,1)=1000.
      EXT(4,1)=1500.
      EXT(5,1)=3000.
      EXT(1,2)=200.
      EXT(2,2)=500.
      EXT(3,2)=1000.
      EXT(4,2)=1500.
      EXT(5,2)=3000.
      EXT(1,3)=200.
      EXT(2,3)=400.
      EXT(3,3)=800.
      EXT(4,3)=1500.
      EXT(5,3)=3000.
      EXT(1,4)=150.
      EXT(2,4)=250.
      EXT(3,4)=500.
      EXT(4,4)=1000.
      EXT(5,4)=2000.
      EXT(1,5)=75.
      EXT(2,5)=150.
      EXT(3,5)=300.
      EXT(4,5)=500.
```

```
                EXT(5,5)=800.
                EXT(1,6)=50.
                EXT(2,6)=100.
                EXT(3,6)=200.
                EXT(4,6)=200.
                EXT(5,6)=200.
                EXT(1,7)=0.0
                EXT(2,7)=0.0
                EXT(3,7)=0.0
                EXT(4,7)=0.0
                EXT(5,7)=0.0
                SLOPE(1,1)=10.
                SLOPE(2,1)= 8.
                SLOPE(3,1)= 5.
                SLOPE(4,1)= 3.
                SLOPE(5,1)= 0.
                SLOPE(1,2)=15.
                SLOPE(2,2)=13.
                SLOPE(3,2)=10.
                SLOPE(4,2)= 5.
                SLOPE(5,2)= 0.
                SLOPE(1,3)=20.
                SLOPE(2,3)=18.
                SLOPE(3,3)=15.
                SLOPE(4,3)=10.
                SLOPE(5,3)= 0.
                SLOPE(1,4)=25.
                SLOPE(2,4)=23.
                SLOPE(3,4)=20.
                SLOPE(4,4)=15.
                SLOPE(5,4)= 5.
                SLOPE(1,5)=35.
                SLOPE(2,5)=30.
                SLOPE(3,5)=25.
                SLOPE(4,5)=25.
                SLOPE(5,5)=20.
                SLOPE(1,6)=45.
                SLOPE(2,6)=40.
                SLOPE(3,6)=35.
                SLOPE(4,6)=40.
                SLOPE(5,6)=40.
                SLOPE(1,7)=400.
                SLOPE(2,7)=400.
                SLOPE(3,7)=400.
                SLOPE(4,7)=400.
                SLOPE(5,7)=400.
C************FIND MAXIMA OF CORRECTED NOISE SPECTRUM************
C
                DO 10 K=1,20
                SOM(K) = 0.0
                MSK(K) = 0.0
             10 MAX(K) = 0.0
                DO 25 K=2,19
                MCNT = K
                PCNT = K
                IF(MAX(K).EQ.0)110,25
            110 KM1=K-1
```

```
          KP1=K+1
          IF(CNL(K).GT.CNL(KM1).AND.CNL(K).GT.CNL(KP1))11,13
       11 MAX(K) = FREQ(K)
          GO TO 25
       13 MCNT = MCNT - 1
          IF(MCNT.EQ.0)17,15
       15 IF(CNL(MCNT).EQ.CNL(K))113,17
      113 MAX(K) = 1.0
          GO TO 13
       17 PCNT = PCNT + 1
          IF(PCNT.GT.20)24,12
       12 IF(CNL(PCNT).EQ.CNL(K))117,19
      117 MAX(K) = 1.0
          GO TO 17
C
C         THE CORRECTED NOISE SPECTRUM LEVEL IS CONSTANT FROM LAST
C         VALUE OF MCNT TO LAST VALUE OF PCNT
C
C         NOW FIND OUT IF SPECTRUM DROPS ON BOTH ENDS OF FLAT SECTION
       19 IF(MCNT.LT.2)24,20
       20 IF(CNL(MCNT).LT.CNL(K).AND.CNL(PCNT).LT.CNL(K))21,24
       21 MAX(K) = SQRT (FREQ(MCNT)*FREQ(PCNT))
       24 CONTINUE
       25 CONTINUE
          IF(CNL(20).GT.CNL(19))800,801
      800 MAX(20) = FREQ(20)
      801 CONTINUE
C
C**********FREQUENCIES OF MAXIMA OF CORRECTED NOISE SPECTRUM NOW
C                ARE THE ONLY VALUES OF MAX(K) THAT ARE NOT ZERO OR ONE
C
          DO 100 K=1,20
          IF(MAX(K).GT.1.0)27,100
C
C         FIND POINT TO THE RIGHT OF MAX(K) THAT IS 3 DECIBELS DOWN
C
       27 TEST = CNL(K) - 3.0
          PCNT = K+1
          STRT=0.0
          DO 40 I=PCNT,20
          IF(CNL(I).EQ.TEST)28,29
       28 STRT=FREQ(I)
          GO TO 141
       29 IF(CNL(I).LT.TEST)30,40
       30 IM1=I-1
C         PROPORTION FREQUENCY INTERVAL FROM LOGARITHMIC SLOPE
C
          BGDLN=CNL(IM1)-CNL(I)
          BGDLF=FREQ(I)-FREQ(IM1)
          DELF=3.0*BGDLF/BGDLN
          STRT=FREQ(IM1) + DELF
          GO TO 141
       40 CONTINUE
          IF(STRT.EQ.0.0) 140,141
      140 STRT = FREQ(20)
C
C         TABLE LOOK-UP OF EXTENSION OF FREQUENCY FROM STARTING POINT,
```

```
C       TABLE LOOK-UP OF SLOPE OF LINE FROM STARTING POINT
C
  141 IF(TEST.GT.95)41,42
   41 L=1
      GO TO 53
   42 IF(TEST.GT.85)43,44
   43 L=2
      GO TO 53
   44 IF(TEST.GT.75)45,46
   45 L=3
      GO TO 53
   46 IF(TEST.GT.65)47,48
   47 L=4
      GO TO 53
   48 IF(TEST.GT.55)49,50
   49 L=5
      GO TO 53
   50 IF(TEST.GT.45)51,52
   51 L=6
      GO TO 53
   52 L=7
   53 IF(STRT.LT.800)54,55
   54 J=1
      GO TO 62
   55 IF(STRT.LT.1600)56,57
   56 J=2
      GO TO 62
   57 IF(STRT.LT.2400)58,59
   58 J=3
      GO TO 62
   59 IF(STRT.LT.3200)60,61
   60 J=4
      GO TO 62
   61 J=5
   62 TERMF=STRT + EXT(J,L)
C
C       ESTABLISH SLOPE AND INTERCEPT OF LOW FREQUENCY PART
C       OF SPREAD-OF-MASKING CURVE
C
      A= -14.43
      B=TEST + 14.43*ALOG(STRT)   - 57.0
C
C       ESTABLISH SLOPE AND INTERCEPT OF HIGH FREQUENCY PART
C       OF SPREAD-OF-MASKING CURVE
C
      C=SLOPE(J,L)/.693
      D=TEST - C*ALOG(TERMF)
      DO 80 I=1,20
      IF(FREQ(I).LT.STRT )63,64
C
C       ESTABLISH SUM=SLOPE*LN(F) + INTERCEPT EQUATIONS FOR
C       SLOPE-OF-MASKING LINES
C
   63 SOM(I) =A*ALOG(FREQ(I)) + B
      GO TO 65
   64 IF(FREQ(I).GT.TERMF)80,564
  564 SOM(I) =C*ALOG(FREQ(I)) + D
```

```
   65 IF(SOM(I).GT.MSK(I))66,80
   66 MSK(I) = SOM(I)
   80 CONTINUE
C
C     MSK(K) NOW CONTAINS THE MAXIMIM OF (POSSIBLY) SEVERAL
C     SOM(I)
C
  100 CONTINUE
      DO 500 K=1,20
  500 SOM(K) = MSK(K)
C
C     EFFECTIVE MASKING LEVEL EQUALS LARGEST OF CORRECTED
C     NOISE LEVELS AND (POSSIBLY) SEVERAL SPREAD-OF-MASKING
C     LEVELS FROM SEVERAL MAXIMA IN THE CORRECTED NOISE LEVEL
C     SPECTRUM
C
      DO 180 I=1,20
      IF(MSK(I).GT.CNL(I))180,68
   68 MSK(I) = CNL(I)
  180 CONTINUE
      WRITE(6,310)
  310 FORMAT(      /,10X,*  CENTER   CORRECTED   SPREAD-    *,
     1*MASKING*,/,10X,*FREQUENCY    NOISE    OF-MASKING LEVEL*,
     2* OF*,/,10X,*OF BAND       LEVEL    OF NOISE    NOISE*,/,
     310X,*(HERTZ)       (DB)       (DB)        (DB)*)
      WRITE(6,400) (FREQ(I),CNL(I),SOM(I),MSK(I),I=1,20)
  400 FORMAT(10X,F7.1,F10.1,2F11.1)
      RETURN
      END
```

TABLE D-2 LISTING OF TYPICAL RESULTS OF COMPUTER CALCULATION OF AI

TEST CASE
DATA TAKEN FROM FIGURE 2 OF ANSI S3.5

CENTER FREQUENCY OF BAND (HERTZ)	SPECTRUM LEVEL OF SPEECH (DB)	SPECTRUM LEVEL OF NOISE (DB)
270.0	69.0	0.0
380.0	69.0	0.0
490.0	68.0	0.0
630.0	65.0	0.0
770.0	63.0	0.0
920.0	60.0	0.0
1070.0	58.0	0.0
1230.0	55.0	19.0
1400.0	53.0	28.0
1570.0	51.0	39.0
1740.0	49.0	48.0
1920.0	47.0	56.0
2130.0	46.0	65.0
2370.0	44.0	75.0
2660.0	43.0	80.0
3000.0	41.0	80.0
3400.0	40.0	80.0
3950.0	39.0	80.0
4560.0	38.0	76.0
5600.0	37.0	62.0

OASL(DBA) = 92.3 114.5

OVERALL SOUND LEVEL (SPEECH + NOISE, 200 TO 6100 HZ) = 114.5 DBA

CENTER FREQUENCY OF BAND (HERTZ)	CORRECTED NOISE LEVEL (DB)	SPREAD-OF-MASKING OF NOISE (DB)	MASKING LEVEL OF NOISE (DB)
270.0	0.0	65.8	65.8
380.0	0.0	60.9	60.9
490.0	0.0	57.2	57.2
630.0	0.0	53.6	53.6
770.0	0.0	50.7	50.7
920.0	0.0	48.1	48.1
1070.0	0.0	46.0	46.0
1230.0	19.0	43.9	43.9
1400.0	28.0	42.1	42.1
1570.0	39.0	40.4	40.4
1740.0	48.0	38.9	48.0
1920.0	56.0	37.5	56.0
2130.0	67.1	36.0	67.1
2370.0	79.5	34.5	79.5
2660.0	85.8	32.8	85.8
3000.0	86.0	31.1	86.0
3400.0	86.0	29.3	86.0
3950.0	85.8	27.1	85.8
4560.0	80.0	83.0	83.0
5600.0	62.6	83.0	83.0

ARTICULATION INDEX = .40

APPENDIX E

TRANSMISSION OF VIBRATION FROM CREW SEATS TO CREW MEMBER'S HEAD

TRANSMISSION OF VIBRATION FROM CREW SEATS TO CREW MEMBER'S HEAD

Figure E-1 shows a lumped-parameter analog of a human body seated on a vertically vibrated platform. The model is not applicable for high frequencies of vibration of a supporting platform, for which a human body responds as a distributed parameter system, with shear waves, compressional waves, and surface waves propagating throughout a body. The model is applicable for frequencies below about 100 Hz (cycles per second).

Figure E-1 must be modified to include the effects of elastic supports for pilot's buttocks. MIL-S-58095[93] specifies a maximum deflection (for the heaviest pilots) of 1.5 inches for cushions. That corresponds exactly to the mean of measured stiffness values for a seat net which is typical of nets that are being substituted for cushions in helicopter seats (AVSCOM[94]). That stiffness, combined with the weight of the hips-plus-buttocks of a 90th pencentile pilot given by von Gierke, produces a resonance frequency of 5 Hz for hips-plus-buttocks on a seat cushion or on a seat net.

von Gierke[95] reviewed a previously-published model which shows that the resonance frequency of an arm on a shoulder is about 5 Hz, and the resonance frequency of a leg on a hip is about 2 Hz. ASCC[96] reported that the resonance frequency of a head plus torso plus arms on a spinal column is 8.4 Hz. Without the mass of a head and arms, the resonance frequency of a torso on a spine is about 7 Hz. von Gierke reviewed a reference which reported that the resonance frequency of a head on a neck is about 30 Hz. Entering those resonance frequencies in Figure E-1, adding cushion elements, and recognizing that the stiffness of a spine controls vertical transmissibility (with little effect due to a thorax-abdomen system below 100 Hz), results in Figure E-2a.

Slater and Frank[97] pointed out that it is impossible to obtain exact analytical solutions to the equations of motion for a system like the one shown in Figure E-2a (Numerical solutions can be obtained by computerized finite-element and finite-difference calculations). The transmissibility of the system shown in Figure E-2a can be "bracketed" by making two opposing assumptions:

(1) the motion of each of the masses is uncoupled from the motions of all of the other masses;

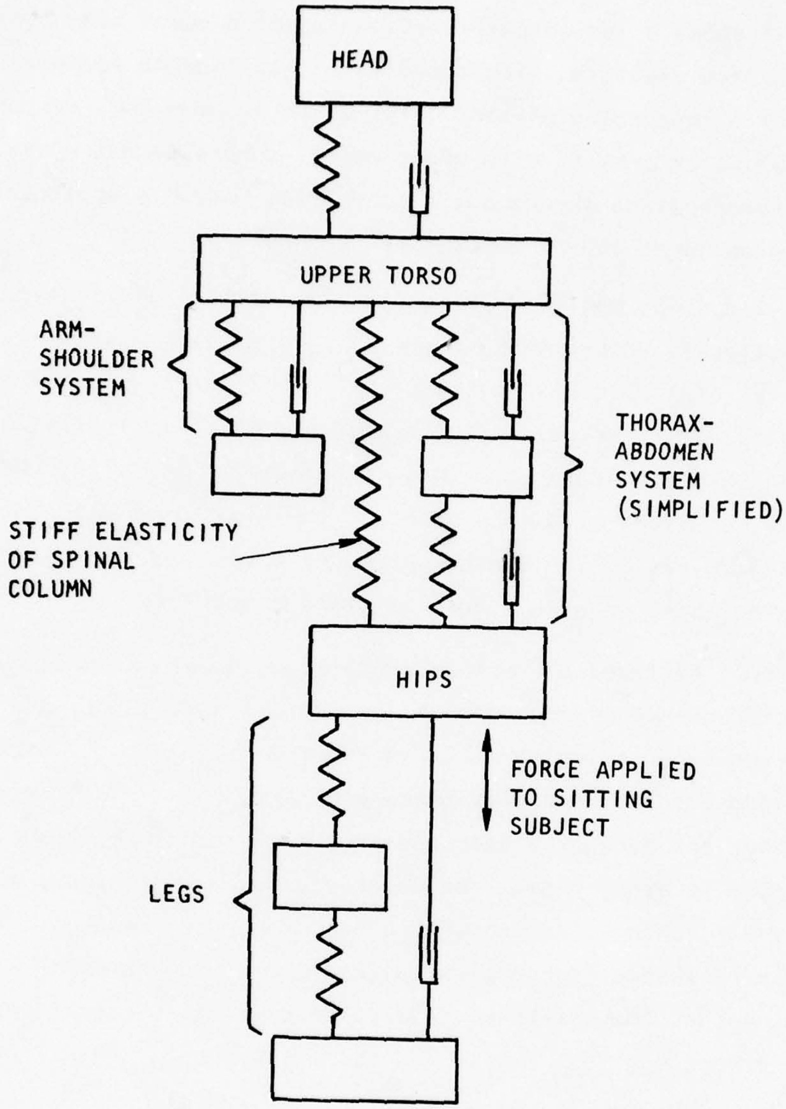
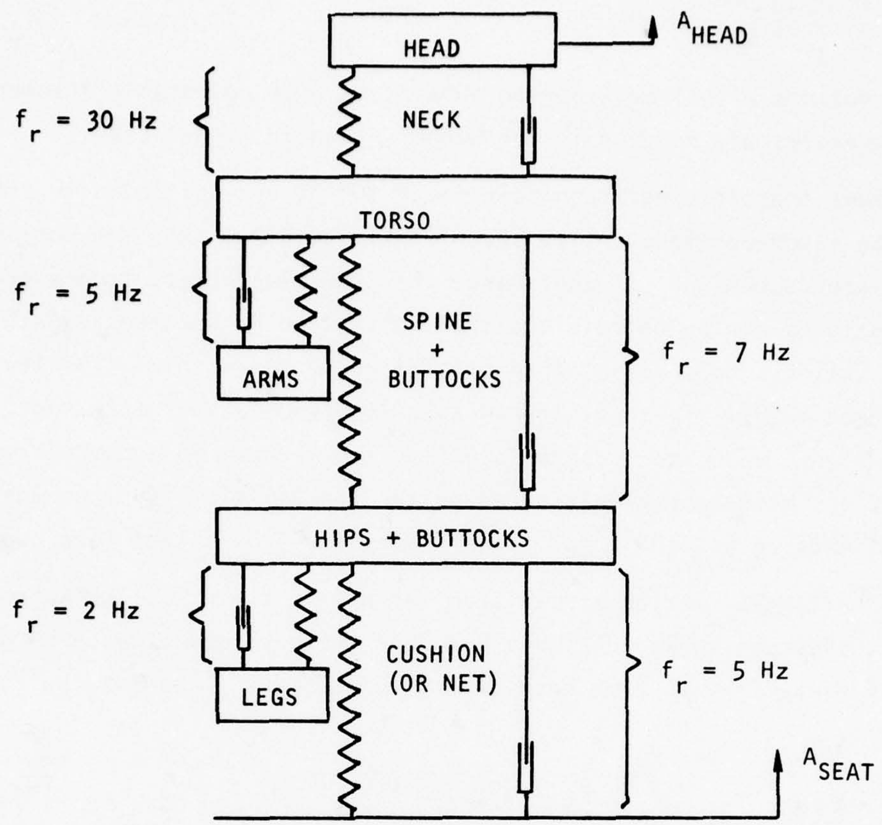
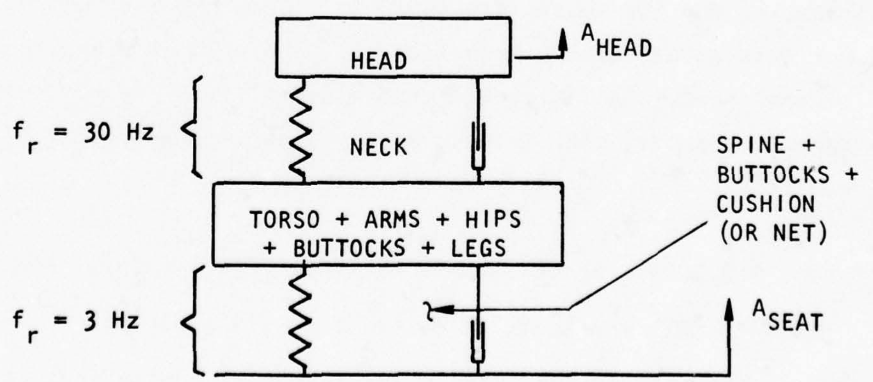


FIGURE E-1 SIMPLIFIED MECHANICAL SYSTEM REPRESENTING A HUMAN BODY SEATED ON A PLATFORM VIBRATING VERTICALLY BELOW 100 Hz.
(FROM COERMANN)[92]



(a) NO LUMPING OF COMPONENTS



(b) WITH LUMPING OF COMPONENTS WITH COMPARABLE RESONANCE FREQUENCIES

FIGURE E-2 TANDEM SYSTEM FOR CALCULATION OF THE TRANSMISSIBILITY OF THE BODY OF A CREW MEMBER SEATED IN A HELICOPTER SEAT

(2) the motions of all mass-spring subsystems with comparable resonance frequencies are coupled in the manner shown in Figure E-2b.

If we assume that driving frequencies near 100 Hz are sufficiently removed from any of the resonance frequencies shown in Figure E-2a, then the motions of the masses are decoupled. In that case, the transmissibility from a seat to hips and buttocks can be calculated, then multiplied by the transmissibility from hips and buttocks to a torso, then multiplied by the transmissibility from a torso to a head to get the total transmissibility from a seat to a head. Similarly, in Figure E-2b, the transmissibility from a seat to a torso/arms/hips/buttocks/legs mass can be multiplied by the transmissibility from that mass to a head mass to get the total transmissibility from a seat to a head.

If the equations of motion are written for any of the decoupled spring-mass-dashpot subsystems shown in Figure E-2, and if those equations are solved for the transmissibility, T, from base excitation to mass response, the result is:

$$T \doteq \frac{A\ \text{mass}}{A\ \text{base}} = \sqrt{\frac{1 + 4\zeta^2\ f^2/fr^2}{f^4/fr^4 + 4\zeta^2\ \dfrac{f^2}{fr^2} - 1}}, \tag{1}$$

where A is acceleration, ζ is the fraction of critical damping at the resonant frequency fr, and f is the frequency of the base oscillations. The fraction of critical damping for the subsystems shown in Figure E-2 is about 0.2.[95,96] that value for ζ is substituted in equation (1), and a 90 Hz vibration of a crew seat is considered, and individual transmissibilities are multiplied in the manner described above, then the two models shown in Figure E-2 yield the following results:

$$\begin{aligned} &A\ \text{head} = 0.0001 \bullet A\ \text{seat, at 90 Hz (from Figure E-2a), and} \\ &A\ \text{head} = 0.002 \bullet A\ \text{seat, at 90 Hz (from Figure E-2b).} \end{aligned} \tag{2}$$

MIL-A-8870[42] states that the level of vibration of a crew seat shall not exceed $\pm$ 1.5g's at frequencies above 86 Hz. Using the transmissibilities defined by equation (2), that level of excitation of a seat translates to peak

accelerations of either 0.00015 g or 0.003 g at a crew member's head. Figure 37 (Section 7 of this report) shows that, if the vibration frequencies are concentrated at about 90 Hz, such accelerations generate sound pressure levels of about 64 dBSPL and 90 dBSPL respectively, inside an earcup (assuming a linear correlation between vibration levels and sound pressure levels). Above 100 Hz the models of Figures 1 and 2 do not apply. One would expect significant decoupling above 100 Hz, leading to less conduction of vibration to the head. The sound pressure levels shown in Figure 37 resulted from vibrations which correspond to lateral vibrations of a pilot's head, while the transmissibilities which are discussed above are for vertical vibrations. However, there tends to be an "equipartition" of vibrational energy within complex mechanical systems, such as an aircraft/pilot/seat system, so the above analysis probably is applicable for lateral vibrations.

More detailed models and equations will have to be constructed to refine the estimates of head vibrations and associated sound pressure levels which are presented above and to extend the analysis to other frequency ranges. However, the calculations which are summarized here serve to demonstrate that seat vibrations may be an important part of the problem with exposure of helicopter pilots to noise (even after A-weighting of sound pressure levels is considered).

APPENDIX F

DERIVATION AND DESCRIPTION OF A FORTRAN IV COMPUTER PROGRAM FOR CALCULATING NOISE REDUCTION BY EARCUPS

APPENDIX F

DERIVATION AND DESCRIPTION OF A FORTRAN IV COMPUTER PROGRAM FOR CALCULATING NOISE REDUCTION BY EARCUPS

Figure F-1a is a simplified drawing of an earcup which is designed to protect an aircraft pilot from noise. If it is assumed that circumaural skin is depressed only under the area where a cushion contacts flesh, then changes in the volume of air enclosed within an earcup can occur even for a rigid cushion, and Zwislocki's[36] analog circuit, shown in Figure F-1b, applies. (See Lindsay[98] for a discussion of electromechanical analogies.) If it is assumed that circumaural skin is depressed uniformly everywhere within the external boundary of the cushion (which requires that the stiffness of the enclosed air is comparable to the stiffness of skin, and that the cartilaginous external ear is sufficiently rigid to drive the underlying flesh to follow air volume variations), then no changes in the volume of air enclosed within an earcup can occur if its earcup cushion is rigid; in that case, the "alternative" analog electrical circuit shown in Figure F-1c applies. In either case, the displacement of air within an ear canal is considered negligible.

Z in Figures F-1b and F-1c denotes specific acoustic impedance,

$Z = |\,Pe\,| / |\,\dot{\xi}\,|$, where

Pe = excess acoustic pressure, and

$\dot{\xi}$ = particle velocity.

The impedances shown in Figure F-1b are

$$Z\ \text{mass} \equiv Zm = \frac{i\omega M}{A_1} \equiv Xm,$$

$$Z\ \text{volume} \equiv Zv = \frac{-i}{\omega}\ \frac{\rho o c^2}{V}\ \left(\frac{So + Si}{2}\right) \equiv iXv,$$

$$Z\ \text{skin} \equiv Zs = \frac{Rc}{(So-Si)}\ \frac{-iKs}{\omega(So-Si)} \equiv rs - iXs, \text{ and}$$

$$Z\ \text{cushion} \equiv Zc = \frac{Rc}{(So-Si)}\ \frac{-iKc}{\omega(So-Si)} \equiv rc - iXc, \text{ where}$$

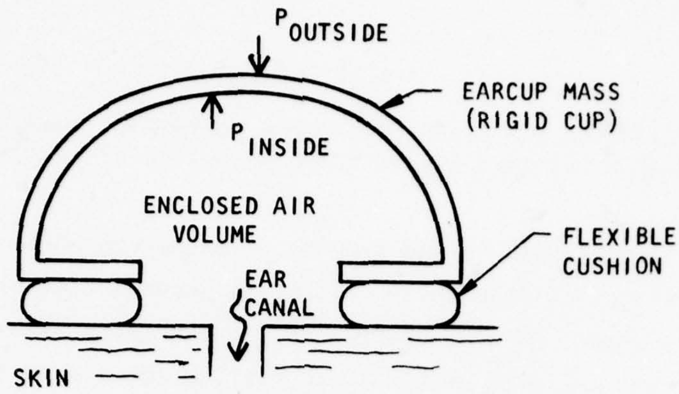
A_1 = effective contact area of cushion[38]

$= \frac{\Pi d_1{}^2}{4}$

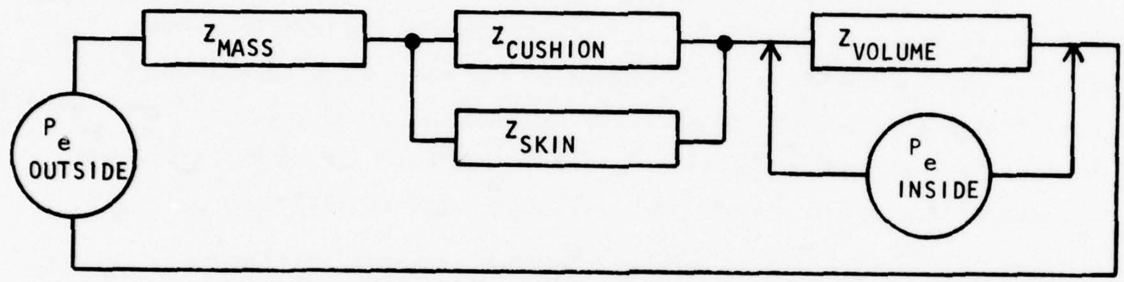
c = velocity of sound within the enclosed air (cm/sec)

do = outer diameter of earcup (cm)

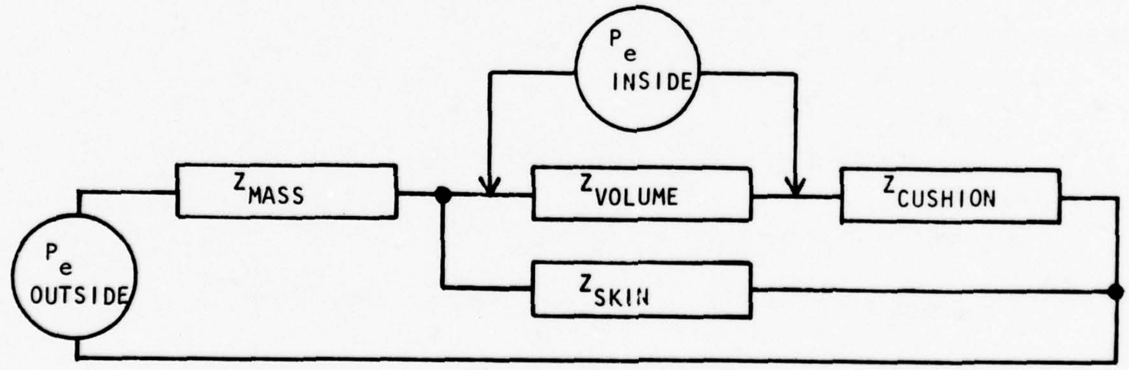
d_i = inner diameter of earcup (cm)



(a) SIMPLIFIED DRAWING OF AN EARCUP



(b) ZWISLOCKI ANALOG CIRCUIT FOR AN EARCUP



(c) ALTERNATIVE ANALOG CIRCUIT FOR AN EARCUP

FIGURE F-1 EARCUP ANALOGS

$d_1 = 1/2(do + di)$

$i = \sqrt{-1}$

Kc = cushion stiffness (dyne/cm)

Ks = skin stiffness (dyne/cm)

M = earcup mass (gm)

Rc = cushion resistance (dyne sec/cm)

Rs = skin resistance (dyne sec/cm)

Si = cross-sectional area of air volume (cm^2)

So = outer cross-sectional area of earcup (cm^2)

$\frac{1}{2}$ (Si + So) = effective cross-sectional area of air volume[38]

V = volume of enclosed air (cm^3)

ρo = density of undisturbed enclosed air (gm/cm^3)

$\omega = 2\pi f = 2\pi$ times the frequency of imposed sound (sec^{-1}).

The impedances shown in Figure $F\text{-}1_c$ are the same as those shown in Figure F-1b, except that

$$Z\ skin \equiv Zs = \frac{Rs}{A_1} - \frac{iKs}{\omega A_1} \equiv rs - iXs.$$

Application of Ohm's law and Kirchoff's laws for electrical circuits to the circuit shown in Figure F-1b yields, after tedious algebraic manipulations:

$$T \equiv |p_{inside}/p_{outside}| = \sqrt{RE^2 + IM^2}, \text{ where}$$

$$RE = \frac{AC - BD}{C^2 + D^2}$$

$$IM = \frac{AD + BC}{C^2 + D^2}, \text{ and}$$

$$A = -Xv\ (Xc + Xs)$$

$$B = Xv(rc + rs)$$

$$C = rcrs - XcXs - XcXv - XvXs + XcXm + XmXs$$

$$D = rcXm + rsXm - rcXs - rsXc - rcXv - rsXv$$

The equivalent results for Figure F-1c are:

$$T \equiv |p_{inside}/p_{outside}| = \sqrt{RE^2 + IM^2}, \text{ where}$$

$$RE = \frac{AXsXv - BrsXv}{A^2 + B^2}$$

$$IM = \frac{ArsXv + BXsXv}{A^2 + B^2}, \text{ and}$$

$$A = XcXs + XvXs - XsXm - XvXm - XcXm - rcrs$$

$$B = rsXm - rsXv - rsXc - rcXs + rcXm$$

The transmission loss, TR, in decibels, exhibited by an earcup like the one shown in Figure F-1a is given by

$$TR = 20 \log_{10} T.$$

Equations supplied by Shaw and Thiessen[38] for Kc were used in the calculations described in this report. However, they recommended using the value for adiabatic compressibility for air within an air-filled cushion of an earcup. That value for air compressibility is not appropriate for small spaces. The value for isothermal compressibility should be used in the calculations, as evidenced by the fact that the match of experimental measurements and computations of the transmission ratio of an earcup with an air-filled cushion (See Section 7.3) was improved when isothermal compressibility was substituted for adiabatic compressibility.

Franke[44] summarized some published measurements of the stiffness and resistance of human mastoids, and Corliss and Koidaw[99] reported some additional measurements. Shaw and Thiessen[38] reported that the stiffness component of the effective circumaural impedance is five or six times smaller than values reported for mastoids. They also reported that the resistance of circumaural flesh is about 10 times greater than values reported for mastoids. The value they reported for circumaural stiffness is:

$$Ks = 8.0 \times 10^7 \text{ dyne/cm}.$$

That value was used in the computer model. Figure F-2 shows the Frequency-dependent values of circumaural resistance which was used in the computer model.

Table F-1 is a listing of a FORTRAN IV computer program for carrying out the calculations which are described above. Table F-2 shows typical tabular print-outs produced by that program, and Figure F-3 shows typical graphical print-outs produced by that program.

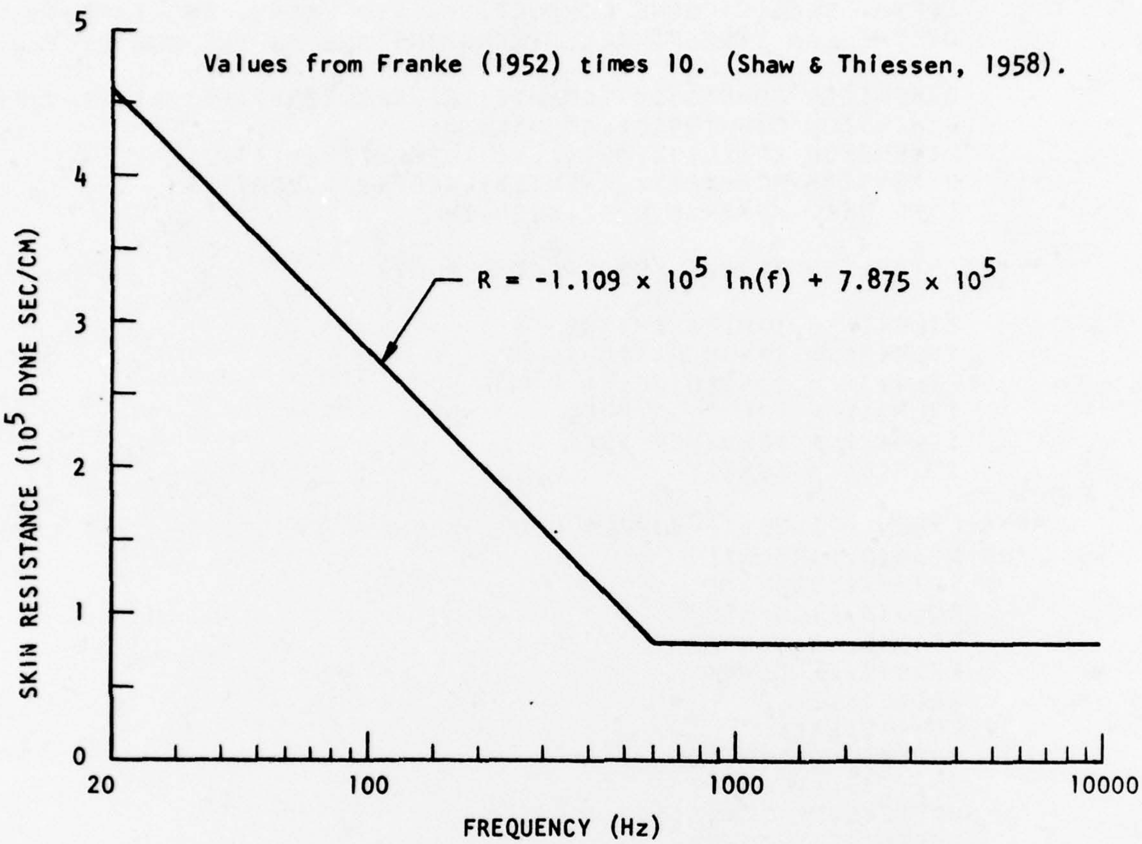


FIGURE F-2 CIRCUMAURAL SKIN RESISTANCE VERSUS FREQUENCY

TABLE F-1


```
      PROGRAM  CUPTR(INPUT,CUTPUT,TAPE 5=INPUT,TAPE 6=OUTPUT)
C
C     CALCULATE NOISE REDUCTION BY PROTECTIVE EARCUPS.
C     INCLUDE EFFECTS OF CONFINED AIR, STIFFNESS AND DAMPING
C     OF FLUID-FILLED EARCUP WALLS, STIFFNESS AND DAMPING OF
C     FLESH. NEGLECT BONE CONDUCTION, AIR LEAKS, AND IMPEDANCE
C     OF THE EAR ITSELF. ALL DIMENSIONS ARE IN THE CGS SYSTEM.
C
      DIMENSION COMNT1(10),COMNT2(10),FREQ(29),ATT(28), TR(28)
      DIMENSION COMNT3(10),COMNT4(10)
      DIMENSION ITITLE(8,8),ITLV(3),ITLH(3),X(29,2)
      DIMENSION RCOP(27), TNEW(27),KCOP(27),VOP(27)
      TYPE REAL KSKIN,M,L,KC,KCOP,IM
C
C*****ESTABLISH TITLES FOR CALCOMP PLOTS
C
      ITLV(1) = 10HTRANSMISSI
      ITLV(2) = 10HON RATIO (
      ITLV(3) = 10HDECIBELS)
      ITLH(1) = 10H      FREQ
      ITLH(2) = 10HUENCY (HER
      ITLH(3) = 10HTZ)
C
C*****LABEL PRINTOUT--SUPPLY FOUR  COMMENT CARDS, COLUMNS 11-62
  300 READ(5,1)COMNT1
    1 FORMAT(10A8)
      READ(5,1)COMNT2
      READ(5,1) COMNT3
      READ(5,1) COMNT4
      WRITE(6,2)
    2 FORMAT(1H1)
      WRITE(6,1)COMNT1
      WRITE(6,1)COMNT2
      WRITE(6,1) COMNT3
      WRITE(6,1) COMNT4
C
C*****READ INPUT(ALL VARIABLES IN CGS DIMENSIONS)********
C
      READ(5,10)M,V,SO,SI,BM
   10 FORMAT(5E15.7)
      READ(5,10)B,H,T,E,RC
      READ(5,10) FLAG,SHUNT
C     M = EARCUP MASS (GRAMS)
C     V = EARCUP AIR VOLUME
C     SO = OUTER CROSS-SECTIONAL AREA OF EARCUP
C     SI = INNER CROSS-SECTIONAL AREA OF OPENING TO VOLUME
C     B = WIDTH OF CONTACT OF FLEXIBLE WALL WITH FLESH
C     H = DEPTH OF FLUID-FILLED WALL BETWEEN EARCUP AND FLESH
C     T = THICKNESS OF WALL MATERIAL
C     E = YOUNG*S MODULUS OF WALL MATERIAL
C     RC = RESISTANCE COEFFICIENT OF FLUID WITHIN THE WALL
C     BM = BULK MODULUS OF THE FLUID WITHIN THE WALL.  IF
C          BM = ZERO, THE FLUID IS ASSUMED INCOMPRESSIBLE.
C     FLAG = 0 FOR FLEXIBLE SKIN, NON-ZERO FOR A RIGID SURFACE.
C     SHUNT = 0 IF SKIN SHUNTS BOTH CUSHION AND VOLUME,
C                NON-ZERO IF SKIN SHUNTS ONLY CUSHION
C
```

```
      IF(FLAG.EQ.0.0) 2200,315
 2200 IF(SHUNT.EQ. 0.0)1300,310
 1300 WRITE(6,301)
  301 FORMAT(/,10X,*SKIN SHUNTS BOTH CUSHION AND VOLUME*)
      GO TO 315
  310 WRITE(6,302)
  302 FORMAT(/,10X,*SKIN SHUNTS CUSHION, BUT NOT VOLUME*)
C
C*****LIST INPUT
  315 WRITE(6,20) M
   20 FORMAT(/,10X,*EARCUP MASS = *,F6.1,* GRAMS*)
      WRITE(6,25)V
   25 FORMAT(/,10X,*EARCUP AIR VOLUME = *,F6.1,* CC+S*)
      WRITE(6,30)SO
   30 FORMAT(/,10X,*OUTER CROSS-SECTIONAL AREA OF EARCUP = *,
     1F5.1,* CMSQ*)
      WRITE(6,35)SI
   35 FORMAT(/,10X,*INNER CROSS-SECTIONAL AREA OF OPENING TO*,
     1* VOLUME = *,F5.1,* CMSQ*)
      WRITE(6,40)B
   40 FORMAT(/,10X,*WIDTH OF CONTACT OF FLEXIBLE WALL WITH*,
     1* FLESH = *,F4.1,* CM*)
      WRITE(6,45)H
   45 FORMAT(/,10X,*DEPTH OF FLUID-FILLED WALL BETWEEN EARCUP*
     1,* AND FLESH = *,F4.1,* CM*)
   50 FORMAT(/,10X,*THICKNESS OF WALL MATERIAL = *,F5.3,* CM*)
      WRITE(6,50)T
      WRITE(6,55)E
   55 FORMAT(/,10X,*YOUNG+S MODULUS OF WALL MATERIAL = *,E9.2,
     1* DYNES/CMSQ*)
      WRITE(6,60)RC
   60 FORMAT(/,10X,*RESISTANCE COEFFICIENT OF FLUID WITHIN*,
     1* THE WALL = *,E9.2,* DYNE SEC/CM*)
      IF(BM.EQ.0.0) 64,63
   63 WRITE(6,65) BM
   65 FORMAT(/,10X,*BULK MODULUS OF FLUID WITHIN THE WALL =*,
     1E9.2,* DYNES/CMSQ*)
      GO TO 79
   64 WRITE(6,62)
   62 FORMAT(/,10X,*INCOMPRESSIBLE FLUID IN EARCUP WALLS*)
   79 IF(FLAG.EQ.0.0) 166,162
  162 WRITE(6,165)
  165 FORMAT(/,10X,*EARCUP ON A RIGID SURFACE*)
      GO TO 170
  166 WRITE(6,167)
  167 FORMAT(/,10X,*KSKIN=8.0E7 DYNES/CM*,
     1*(SHAW AND T.,JASA,1958)*)
      WRITE(6,168)
  168 FORMAT(/,10X,*FREQUENCY-DEPENDENT RSKIN FROM *,
     1*FRANKE(JASA,1952)*,
     2/,10X,*TIMES 10(SHAW AND T.,JASA,1958)*)
C
C*****COMPUTE CONSTANTS
  170 BTM = (SO - SI)
      L =1.7725*(SQRT(SO)+SQRT(SI))
      AL = L*L/12.5664
      IF(BM.EQ.0.0) 67,66
```

```
         66 KC = (B*B*L*BM)/(B*H + .7854*H*H)
            GO TO 78
         67 KC= 1.27324*B*B*L*E*T/(H**3.0)
      C
      C*****SUPPLY CONSTANTS
         78 TWPI=6.2831853
            RHO = 1.293E-03
            C = 33968.44
            IF(FLAG.EQ.0.0) 210,220
        210 KSKIN = 8.0E+07
      C     SHAW AND THIESSEN(JASA,1958)
            GO TO 68
        220 KSKIN = 6.7E+17
      C     RIGID SURFACE
            RSKIN= 1.0E+14
      C     RIGID SURFACE
      C
      C*****COMPUTE CUSHION RESISTANCE
      C
         68 RC= RC/BTM
      C
      C*****COMPUTE REACTANCES AND TRNS. RATIO FOR EACH FREQUENCY
      C
            F= 16.0
            DO 500 I=1,27
            F = F*(2**(1.0/3.0))
            FREQ(I) = F
            IF(FLAG.EQ.0.0)2005,2100
       2005 IF(F.GT.600)2000,2010
      C     RSKIN FROM FRANKE(JASA,1952)
       2000 RSKIN = .8E+04
            GO TO 2100
       2010 RSKIN = -11090.*2.3026*ALOG10(F) +78750.
       2100 RSKIN = 10.*RSKIN
      C   SHAW AND THIESSEN(JASA,1958)
            AF= TWPI*F
            XM = AF*M/AL
            XV = (RHO*C*C/(AF*V))*(SI + SO)/2.
            XC= KC/(AF*(SO-SI))
            IF(SHUNT.EQ.0.0) 498,497
        497 RS = RSKIN/(SO-SI)
            XS= KSKIN/(AF*(SO-SI))
            A = -XV*(XC + XS)
            B = XV*(RC + RS)
            CC= RC*RS -XC*XS -XC*XV -XV*XS +XC*XM +XM*XS
            D = RC*XM +RS*XM -RC*XS -RS*XC -RC*XV -RS*XV
            RE = (A*CC -B*D)/(CC*CC +D*D)
            IM = (A*D +B*CC)/(CC*CC +D*D)
            GO TO 499
        498 RS = RSKIN/AL
            XS = KSKIN/(AL*AF)
            A = XC*XS +XV*XS -XS*XM -XV*XM -XC*XM -RC*RS
            B = RS*XM - RS*XV - RS*XC -RC*XS +RC*XM
            RE =(A*XS*XV - B*RS*XV)/(A*A + B*B)
            IM =(A*RS*XV + B*XS*XV)/(A*A + B*B)
        499 T = SQRT(RE*RE +IM*IM)
        500 TR(I) = 20.0 * ALOG10(T)
```

```
      C
      C*****LABEL AND LIST COMPUTED OUTPUT
      C
            WRITE(6,70)
         70 FORMAT(/,10X,*FREQUENCY  TRANSMISSION RATIO*,/,11X,
           1*(HERTZ)*,7X,*(DECIBELS)*)
            WRITE(6,71)(FREQ(I), TR(I),I=1,27)
         71 FORMAT(10X,F8.1,F14.1)
      C*****SPECIFY LENGTH OF TITLE BLOCK FOR CALCOMP PLOT
       5001 DO 801 I=1,8
        801 ITITLE(I,1) = 35
      C
      C*****READ TITLE CARDS FOR CALCOMP PLOT IN
      C             FIRST 35 SPACES OF EACH OF 8 CARDS
      C
            DO 400 I=1,8
        400 READ(5,810)(ITITLE(I,J),J=2,5)
        810 FORMAT(4A10)
      C
      C*****BUILD PLOT MATRIX
      C
            DO 820 J=2,28
            X(J,2) = FREQ(J-1)
        820 X(J,1) =  TR(J-1)
            X(1,2)= 11.
            X(29,2)=  9999.
            X(1,1) = 29.9
            X(29,1) = -149.9
      C
      C*****CALL CALCOMP PLOT ROUTINE
      C
            CALL PLTLOG(1,3,X,29,29,1,2,ITLV,30,1,ITLH,30,IT1,NIT1,
           1           IT2,NIT2,IT3,NIT3,IT4,NIT4,IT5,NIT5,8,
           2           ITITLE,8,0)
      C
      C*********ONE CARD AFTER EACH DATA SET. CARD READS 999. IN
      C          FIRST TEN COLUMNS AFTER LAST SET OF DATA.
      C
            READ(5,100)TEST
        100 FORMAT(10F8.2)
            IF(TEST.EQ.999)200,300
        200 CONTINUE
            STOP
            END
```

TABLE F-2A

COMPUTED TRANSMISSION RATIO VS. FREQUENCY FOR THE EARCUP
SHOWN IN FIGURE 11 OF SHAW AND T. (JASA,1958).
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.

EARCUP MASS = 490.0 GRAMS

EARCUP AIR VOLUME = 105.0 CC*S

OUTER CROSS-SECTIONAL AREA OF EARCUP = 67.3 CMSQ

INNER CROSS-SECTIONAL AREA OF OPENING TO VOLUME = 18.9 CMSQ

WIDTH OF CONTACT OF FLEXIBLE WALL WITH FLESH = 2.8 CM

DEPTH OF FLUID-FILLED WALL BETWEEN EARCUP AND FLESH = 1.1 CM

THICKNESS OF WALL MATERIAL = .025 CM

YOUNG*S MODULUS OF WALL MATERIAL = .33E+09 DYNES/CMSQ

RESISTANCE COEFFICIENT OF FLUID WITHIN THE WALL = .40E+06 DYNE SEC/CM

INCOMPRESSIBLE FLUID IN EARCUP WALLS

EARCUP ON A RIGID SURFACE ←

FREQUENCY (HERTZ)	TRANSMISSION RATIO (DECIBELS)
20.2	-30.1
25.4	-30.1
32.0	-30.0
40.3	-29.9
50.8	-29.8
64.0	-29.6
80.6	-29.2
101.6	-28.6
128.0	-27.6
161.3	-25.8
203.2	-22.8
256.0	-22.3
322.5	-29.4
406.4	-35.8
512.0	-41.2
645.1	-46.0
812.7	-50.4
1024.0	-54.7
1290.2	-58.9
1625.5	-63.0
2048.0	-67.1
2580.3	-71.2
3251.0	-75.2
4096.0	-79.2
5160.6	-83.3
6502.0	-87.3
8192.0	-91.3

VMIN= .1100E+02 VMAX= .9999E+04

TABLE F-2B

COMPUTED TRANSMISSION RATIO VS. FREQUENCY FOR THE EARCUP
SHOWN IN FIGURE 11 OF SHAW AND T. (JASA,1958).
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.

SKIN SHUNTS CUSHION, BUT NOT VOLUME

EARCUP MASS = 490.0 GRAMS

EARCUP AIR VOLUME = 105.0 CC'S

OUTER CROSS-SECTIONAL AREA OF EARCUP = 87.3 CMSQ

INNER CROSS-SECTIONAL AREA OF OPENING TO VOLUME = 18.9 CMSQ

WIDTH OF CONTACT OF FLEXIBLE WALL WITH FLESH = 2.8 CM

DEPTH OF FLUID-FILLED WALL BETWEEN EARCUP AND FLESH = 1.1 CM

THICKNESS OF WALL MATERIAL = .025 CM

YOUNG'S MODULUS OF WALL MATERIAL = .33E+09 DYNES/CMSQ

RESISTANCE COEFFICIENT OF FLUID WITHIN THE WALL = .40E+06 DYNE SEC/CM

INCOMPRESSIBLE FLUID IN EARCUP WALLS

KSKIN=6.0E7 DYNES/CM(SHAW AND T.,JASA,1958)

FREQUENCY-DEPENDENT RSKIN FROM FRANKE(JASA,1952)
TIMES 10(SHAW AND T.,JASA,1958)

FREQUENCY (HERTZ)	TRANSMISSION RATIO (DECIBELS)
20.2	-8.0
25.4	-7.9
32.0	-7.7
40.3	-7.5
50.8	-7.2
64.0	-7.3
80.6	-8.9
101.6	-12.5
128.0	-17.0
161.3	-21.6
203.2	-26.1
256.0	-30.4
322.5	-34.7
406.4	-38.9
512.0	-43.0
645.1	-47.1
812.7	-51.1
1024.0	-55.1
1290.2	-59.2
1625.5	-63.2
2048.0	-67.2
2580.3	-71.2
3251.0	-75.3
4096.0	-79.3
5160.6	-83.3
6502.0	-87.3
8192.0	-91.3

FIGURE F-2C

COMPUTED TRANSMISSION RATIO VS. FREQUENCY FOR THE EARCUP
SHOWN IN FIGURE 11 OF SHAW AND T. (JASA,1958).
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.

SKIN SHUNTS BOTH CUSHION AND VOLUME ←

EARCUP MASS = 490.0 GRAMS

EARCUP AIR VOLUME = 105.0 CC'S

OUTER CROSS-SECTIONAL AREA OF EARCUP = 87.3 CMSQ

INNER CROSS-SECTIONAL AREA OF OPENING TO VOLUME = 18.9 CMSQ

WIDTH OF CONTACT OF FLEXIBLE WALL WITH FLESH = 2.8 CM

DEPTH OF FLUID-FILLED WALL BETWEEN EARCUP AND FLESH = 1.1 CM

THICKNESS OF WALL MATERIAL = .025 CM

YOUNG'S MODULUS OF WALL MATERIAL = .33E+09 DYNES/CMSQ

RESISTANCE COEFFICIENT OF FLUID WITHIN THE WALL = .40E+06 DYNE SEC/CM

INCOMPRESSIBLE FLUID IN EARCUP WALLS

KSKIN=9.0E7 DYNES/CM(SHAW AND T.,JASA,1958)

FREQUENCY-DEPENDENT RSKIN FROM FRANKE(JASA,1952)
TIMES 10(SHAW AND T.,JASA,1958)

FREQUENCY (HERTZ)	TRANSMISSION RATIO (DECIBELS)
20.2	-29.5
25.4	-29.3
32.0	-29.0
40.3	-28.6
50.8	-28.3
64.0	-28.2
80.6	-28.9
101.6	-30.7
128.0	-33.4
161.3	-36.8
203.2	-40.4
256.0	-44.3
322.5	-48.4
406.4	-52.8
512.0	-57.6
645.1	-62.1
812.7	-65.5
1024.0	-69.0
1290.2	-72.7
1625.5	-76.5
2048.0	-80.4
2580.3	-84.3
3251.0	-88.3
4096.0	-92.3
5161.6	-96.2
6502.0	-100.2
8192.0	-104.2

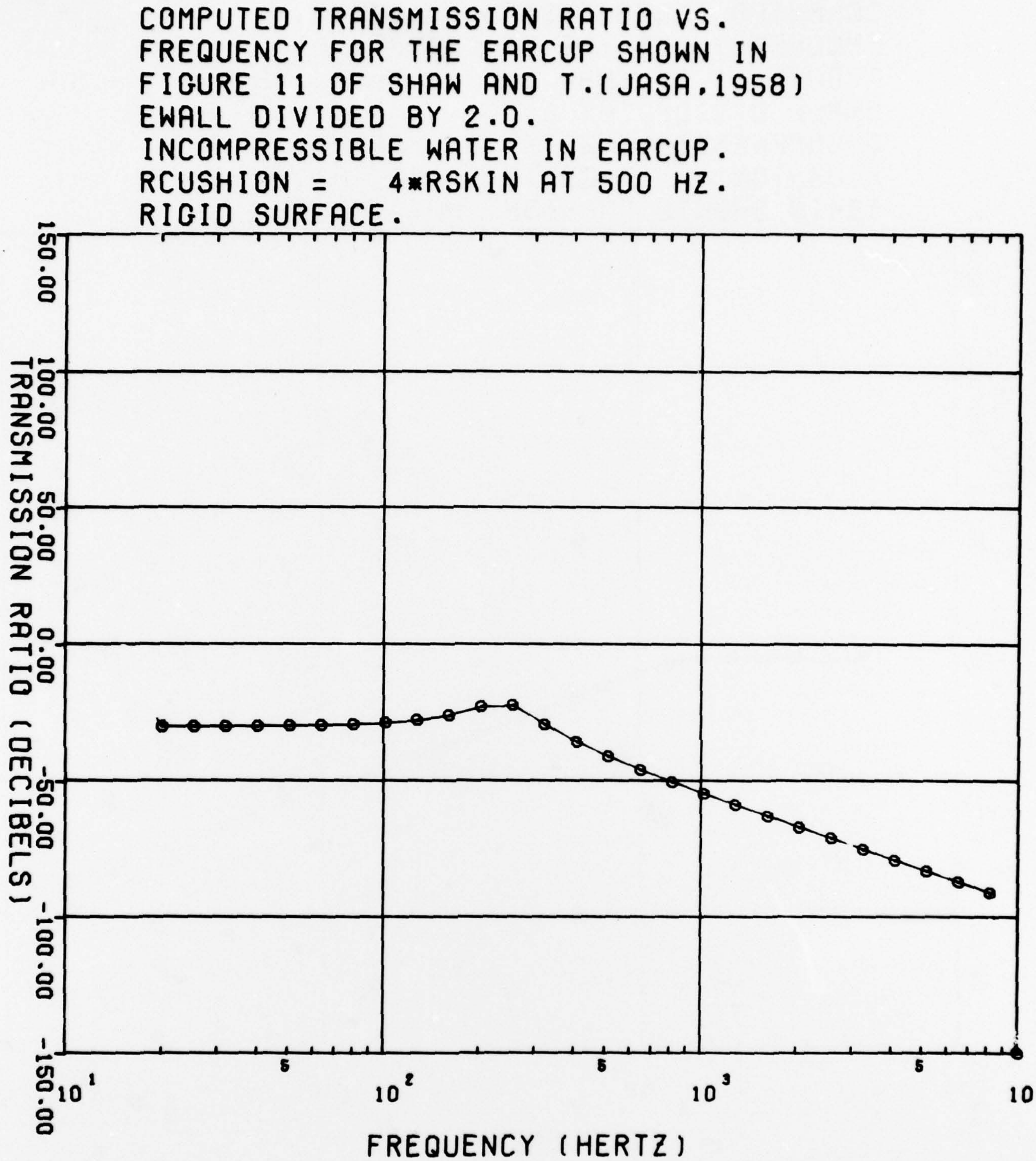

COMPUTED TRANSMISSION RATIO VS.
FREQUENCY FOR THE EARCUP SHOWN IN
FIGURE 11 OF SHAW AND T.(JASA,1958)
EWALL DIVIDED BY 2.0.
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.
RIGID SURFACE.
150.00
100.00
50.00
0.00
-50.00
-100.00
-150.00
TRANSMISSION RATIO (DECIBELS)
10 1
5
10 2
5
10 3
5
10 4
FREQUENCY (HERTZ)

FIGURE F-3A

COMPUTED TRANSMISSION RATIO VS.
FREQUENCY FOR THE EARCUP SHOWN IN
FIGURE 11 OF SHAW AND T.(JASA,1958)
EWALL DIVIDED BY 2.0.
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.
ZSKIN SHUNTS CUSHION, NOT VOLUME.

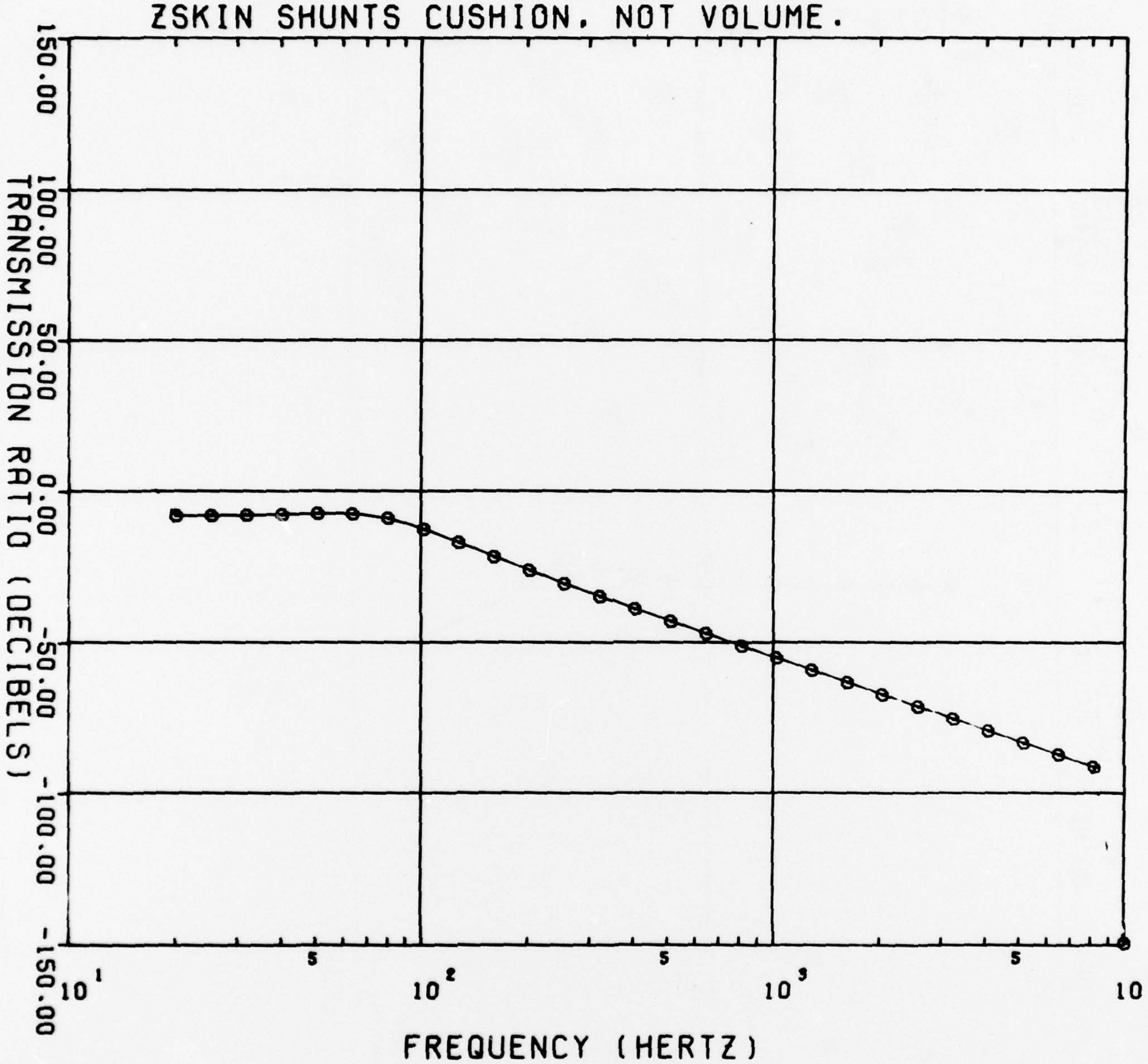


FIGURE F-3B

COMPUTED TRANSMISSION RATIO VS.
FREQUENCY FOR THE EARCUP SHOWN IN
FIGURE 11 OF SHAW AND T.(JASA,1958)
EWALL DIVIDED BY 2.0.
INCOMPRESSIBLE WATER IN EARCUP.
RCUSHION = 4*RSKIN AT 500 HZ.
ZSKIN SHUNTS CUSHION AND VOLUME.

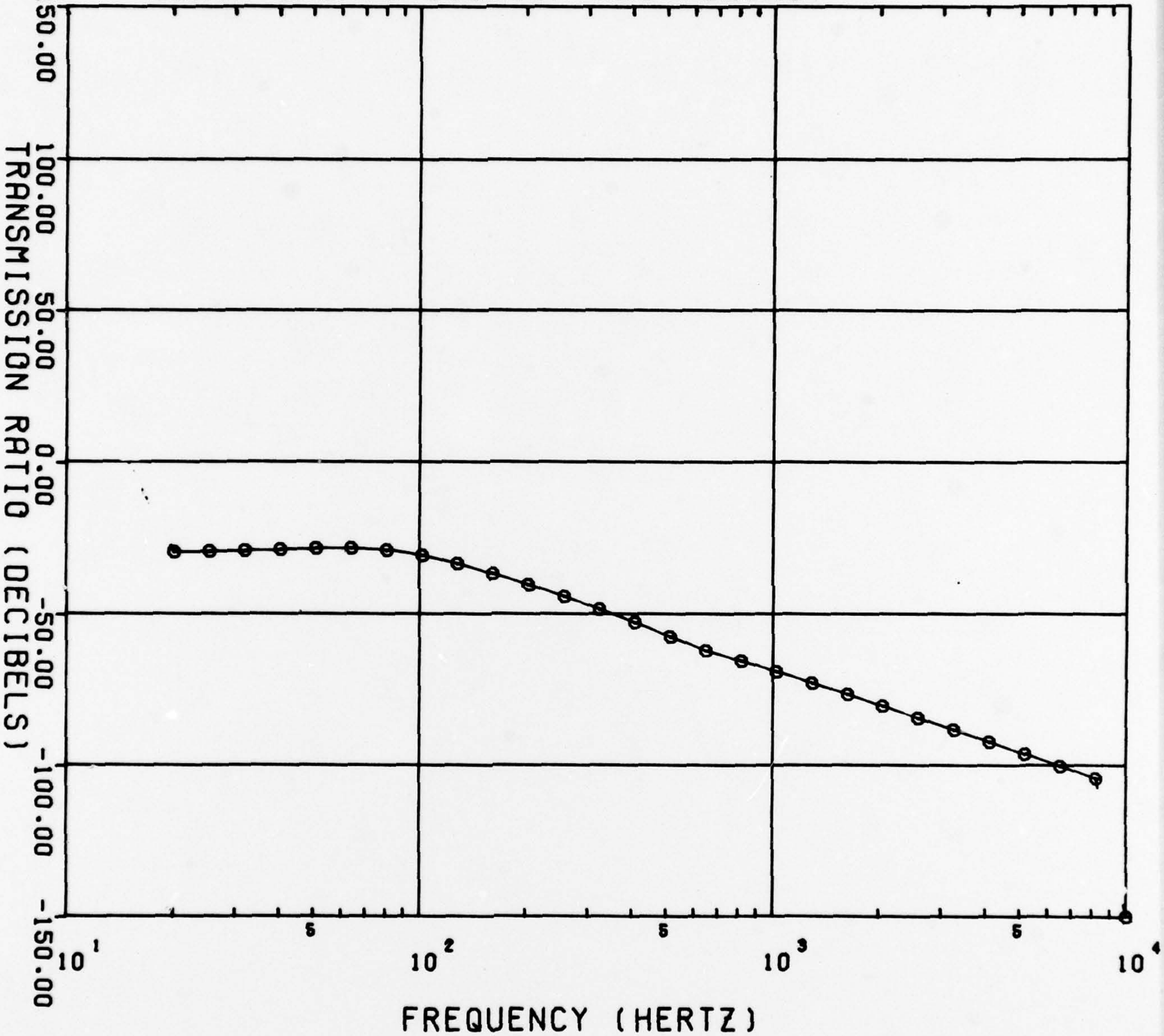


FIGURE F-3C

APPENDIX G

ANALYTICAL OPTIMIZATION OF THE DESIGN OF EAR PROTECTORS

ANALYTICAL OPTIMIZATION OF THE DESIGN OF EAR PROTECTORS

The function

$$T(Xc,\ rc,\ Xv) \equiv \left|\frac{P_{inside}}{P_{outside}}\right| = (RE^2 + IM^2)^{1/2} \quad ,$$

which is defined in Appendix F, attains a maximum <u>or</u> a minimum for those values of Xc, rc, and Xv for which $\partial T/\partial Xc$, $\partial T/\partial rc$, and $\partial T/\partial Xv$ go to zero simultaneously (Solkolnikoff and Redheffer,[100]). Carrying out the indicated partial differentiations for the transmission ratio defined in Appendix F for the Zwislocki model which is shown in Figure F-1, and setting the resulting derivatives equal to zero, yields (after tedious algebraic manipulations):

$$Xc = \frac{XvXs^2 - XmXs^2 + (1.0 - \frac{1.0}{T^2})Xv^2Xs - 2XvXsXm + Xm^2Xs - rs^2Xm + rs^2Xv}{(-Xs^2 - 2XsXv + (\frac{1.0}{T^2} - 1)Xv^2 + 2XsXm + 2XvXm - Xm^2 - rs^2)} \qquad (1)$$

$$rc = \frac{rs\ (Xm^2 - 2XvXm + \{1.0 - \frac{1.0}{T^2}\}\ Xv^2)}{(rs^2 + Xm^2 - 2XsXm - 2XvXm + 2XsXv + Xs^2 + Xv^2)} \qquad (2)$$

$$Xv = \frac{rcrsXs - 2XcXs^2 + 2XcXmXs + 2XmXs^2 + rc^2Xm + 2rsrcXm - rc^2Xs - rcrsXc + rs^2\ (Xm - Xc)}{2XcXs + 2Xs^2 + 2rsrc + rc^2 + rs^2 - \frac{(Xc+Xs)^2 + (rc+rs)^2}{T^2}} \qquad (3)$$

If equations (1), (2), and (3) are solved simultaneously, values for Xc, rc, and Xv which cause T to take on extreme (locally maximum or minimum) values are obtained. The three simultaneous equations must be solved for each frequency of interest, and additional calculations must be performed to ascertain whether an extreme value is a locally maximized value, a locally minimized value, the highest of all local maxima, or the lowest of all local minima. Obviously, an electronic computer will be required for the optimization calculations.